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COMPARATIVE DOWNWASH AND SIMULATED FOREST RESCUE TESTS OF THE HH-3E, HH-53B AND THE XC-142A AIRCRAFT

December 1967

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ABSTRACT

Tests were performed at Eglin AFB with an HH-3E, an HH-53B and an XC-142A to determine comparative downwash characteristics of the three VTOL aircraft. Simulated forest rescues were also made. Downwash velocities, sound pressure levels, temperatures, toxic hazards and relative freedom of movement of human subjects were measured and/or observed for various hover conditions.

This report has been reviewed and is approved.

James H. Stephenson

LT COL JAMES H. STEPHENSON
Test Director

-A-

INTRODUCTION

1.0 This report presents the details and results of the V/STOL Aircraft Downwash Characteristics and Simulated Forest Rescue Tests conducted at Eglin Air Force Base Florida, 21-25 August 1967 with an HH-3E, an HH-53B and an XC-142A. The downwash tests were conducted in response to a request from Dr. Alexander H. Flax, Assistant Secretary of the Air Force (Research and Development).

In the past, downwash velocity has been investigated both through the use of aerodynamic and momentum theory and by means of tests employing full scale and reduced scale propellers and rotors. Most of these investigations, however, were conducted to determine the effects of the downwash on the aircraft itself, or to determine the erosion effects on the terrain or landing site. There was little information available concerning the effects of downwash velocity on men performing rescue operations or other tasks beneath the hovering aircraft. Also, there was little or no information which could be used to verify the accuracy of theoretical calculations of downwash velocities beneath V/STOL aircraft of various configurations.

The purpose of this test was to evaluate aircraft with different disc loadings in the rescue recovery role over open and over forest terrain and to quantitatively determine the downwash characteristics and other environmental values under representative V/STOL aircraft. The HH-3E helicopter is a USAF rescue aircraft which has been in use in Southeast Asia (SEA) for several years. The HH-53B helicopter is just entering rescue service with the USAF in SEA and is expected to provide greater rescue capability than the lighter, slower HH-3E. The XC-142A is an experimental tilt wing aircraft which was produced to determine the operational suitability and capability of the V/STOL tilt wing concept. These three aircraft had average disc loadings of 5.51 lb/ft^2, 8.55 lb/ft^2, and 41.5 lb/ft^2, respectively during the tests.

The quantitative data which were collected in the instrumented open area, were for comparison with predictions of maximum downwash velocities and downstream velocity decay rates based on aerodynamic and momentum theory. After the open area tests were completed, some of the instrumentation was moved to the forest area in order to measure the effects of the vegetation on the downwash and to be able to correlate, if possible, the baseline data from the open area with the capability to perform a rescue in the forest. Representatives of the 6570th Aerospace Medical Research Laboratories performed various functions beneath the hovering aircraft both in the open area and the forest area. Air samples were collected in the open area and blood samples were taken from subjects in and beneath the aircraft to determine whether or not there were any toxic hazards from exhaust products.

Outstanding cooperation by many organizations in addition to the Aerospace Medical Research Laboratories, contributed to the accomplishment of this test program and this cooperation is gratefully acknowledged:

Air Force Flight Dynamics Laboratory
Air Force Flight Test Center, AFSC
Air Proving Ground Center, AFSC
1365th Photo Sqd., MAC
48th Aerospace Rescue and Recovery Sqd., MAC
Air Weather Service, MAC
Vought Aeronautics Div., L.T.V.
Sikorsky Aircraft Div., U.A.C.

SUMMARY

2.0 This section presents a brief account of the V/STOL downwash tests and summary of the results.

There were many factors influencing the schedule and the execution of the tests. It was desired to have the tests completed and the preliminary results distributed as soon as possible. All of the aircraft involved in the tests were diverted from other projects or missions on a noninterference basis and could not be made available indefinitely. The HH-3E, HH-53B, and UH-1F (providing aerial photographic coverage) helicopters were involved in high priority training and testing in support of SEA, while the XC-142A was required to complete the final portions of the Tri-Service test program under AF contract AF 33(657)-7868. It was also desirable to complete the tests in as short a time span as possible to avoid large differences in weather conditions.

For these reasons, it was decided to use instrumentation that was readily available or which could be fabricated quickly, to integrate the downwash test schedule with the Eglin SEA test and training schedule minimizing the impact on it, and to collect the best data possible in one week without waiting for ideal and identical weather conditions for each flight. The primary wind velocity instruments available in Air Force supply were 11 propeller driven anemometers furnished by Air Weather Service. The Vought Aeronautics Division, LTV Aerospace Corporation, constructed and installed 6 pressure rakes to measure dynamic pressure for use in determining wind velocity. Additional instrumentation was installed by both government and LTV personnel to measure sound, temperature, and pressure levels. Details concerning the instrumentation are given in subsequent sections of this report.

The week of 11-15 August 1967, was spent preparing the open area test site and installing and calibrating the instrumentation. The open area tests were conducted over the north-south runway at Eglin AFB Auxiliary Field No. 4. This site provided a large area free of obstructions which might distort the flow of the prevailing wind or cause blockage of the downwash flow. It also provided a hard surface which reduced the problem of sand, dust and debris being blown about.

Preparation of the site included laying out the instrumentation pattern and marking the hover points. The instrumentation pattern was laid out on north-south east-west axes to coincide with the expected prevailing wind at test time. The anemometers and pressure rakes were installed by driving stakes through holes in base plates and attaching

guy wires for side loads. Other instrumentation was attached to the pressure rakes and anemometer stands. The tubing and electrical leads from the instrumentation pick-ups to the recorders in the vans about 200 ft away were fastened to the runway by spikes and tape or heavy cord. Three-foot diameter circles were painted on the runway for each aircraft at each hover point. These circles were placed so that when the aircraft was hovering with the forest penetrator in the circle, the center of the rotor or propeller system would be over ground zero in the instrumentation grid.

The HH-3E helicopter flew a dry run on 21 August to clean off the runway and check out the instrumentation and test procedures. The pressure rake probes were covered with the tape while the HH-3E flew at a low altitude over the instrumented area to blow away any loose sand, dirt or other matter. After the area was clean the tape was removed from the pressure rake probes and the hoist cable on the helicopter was marked to permit its use in establishing hover altitude.

The test plan called for data to be recorded for six different hover points at each of eight different altitudes. The altitudes were 200 ft, 150 ft, 125 ft, 100 ft, 75 ft, 50 ft, 25 ft, and 10 ft above the runway. The six hover points were as follows:

Point	Heading
Ground Zero*	360°
Ground Zero	045°
20 ft East of Ground Zero	360°
40 ft East of Ground Zero	360°
20 ft South of Ground Zero	360°
40 ft South of Ground Zero	360°

*The intersection of north-south and east-west axes is ground zero.

The purpose of the six hover points was to effectively increase the amount of data obtainable from the limited amount of instrumentation. The eight hover altitudes would provide data from the lowest possible hover altitude to a height equal to approximately three rotor diameters for the HH-3E and HH-53B helicopters and approximately 13 propeller diameters for the XC-142A.

During the dry run, the HH-3E started hovering at the 200 ft level and worked down to the lower levels. As it turned out, it was impossible to hover at 75 feet or higher with enough precision to

make use of the four hover points east and south of ground zero. That is, the variations in hover position at the higher altitudes would have caused them to overlap or be separated so much that the resulting scatter would have precluded meaningful comparison. Also, considerably more time was required to establish a stable hover at each altitude than had been anticipated. To have recorded data at all six hover points, then, would have resulted in extending the test time beyond the practical limit with little expectation of achieving any additional benefits. For these reasons the four hover points east and south of ground zero were eliminated from the tests.

Data was recorded during the dry run and the instrumentation checked out satisfactorily. A problem arose concerning the behavior of the anemometers. The turbulence of the downwash under the helicopter caused the anemometer vanes to spin rapidly which, in turn, caused the recording arm to oscillate rapidly. The rapid oscillation of the recording arm caused the wiring circuits to overheat and the thermal relays to pop out. To avoid this, strings were tied to the anemometer vanes restraining rotation to approximately $\pm$ 100° from vertical.

The HH-3E was the first aircraft to be flown over the instrumented area, on the morning of 22 August, in winds not greater than 4 knots. As expected the live test subjects had no difficulty functioning beneath this low disc-loading helicopter.

Following the HH-3E, the HH-53B was hovered over the test area. The downwash pattern was the same as that for the HH-3E with a turbulent "quiet zone" under the center of the rotor and the highest steady velocity under the outboard portion of the blades. The difference in downwash velocity between the two helicopters was quite noticeable and the live test subjects experienced some difficulty, depending on hover height, approaching and passing thru the area of highest velocity. Once inside this area of high velocity downwash, the subjects were able to function with less difficulty. The downwash velocity near the ground was greatest for both helicopters when they were hovering at 50 and 75 feet. Some of the plastic anemometer blades were broken off by the HH-53B downwash at the 25 ft height. Live subjects were not permitted under the HH-53B at the 10 foot height because of possible injury due to an anemometer failure.

The following morning, 23 August, the XC-142A was flown over the test area in wind not exceeding 4 knots. Data were recorded at the higher altitudes first (75 to 200 feet) since it was not known what effect expected higher downwash velocities might have on the instrumentation. The test subjects moved under the aircraft at these

altitudes beneath the left wing while the aircraft was heading 045°. While the downwash velocity was stronger than that of the HH-53B at comparable heights, and the test subjects did experience more difficulty in moving against it, they were able to accomplish the same things that had been accomplished under the helicopters. Subjective comments on action under the three aircraft, (open site and forest test), are given on the two following pages. Since some of the anemometer blades were broken by the XC-142A downwash at 75 feet, the test subjects were not permitted to walk under the aircraft at lower altitudes. Several more anemometer blades were broken during the 50 foot hover so the XC-142A was not flown below this altitude. At this point, there was enough fuel for some additional flight so data were recorded at the six altitudes from 50 feet through 200 feet over a point 15 feet north of ground zero on a heading of 360°.

After the XC-142A had departed the area, it was discovered that only three of the eleven anemometers were still serviceable.

After completion of the XC-142A tests on 23 August, two pressure rakes, the remaining three serviceable anemometers and other instrumentation were transferred to the forest area in preparation for the following day's tests.

The first day of the forest area tests, 24 August, the HH-53B and the XC-142A were flown. The test procedure over the forest was to begin hovering at two hundred foot altitude (130 feet above tree height) and work down recording data at each twenty-five foot increment. Following this, a simulated rescue was performed by hoisting an anthropormorphic dummy through the trees in a horse collar sling. The hoist pickup was to be made at the same altitude for all aircraft. Since it was not known which altitude would be best for the XC-142A pickup and since the HH-53B flew first (the XC-142A was delayed for maintenance), two dummy pickups were made with the HH-53B - one at one-hundred fifty-feet and one at one-hundred twenty-five feet. The HH-53B downwash caused the trees to thrash about violently and broke off bay tree limbs up to two inches in diameter. Two pine trees about five or six inches in diameter were bent over so that they acquired a permanent set, forming an arc with their tops about twenty-five feet from the ground. These trees were about forty feet tall when erect. Downwash from the XC-142A left these same tree tops about 10 feet above the ground. (See Figures 16 and 17).

SUBJECTIVE COMMENTS

Open Site (Field #4)

HH-3
(10 ft to 200 ft)

1) No difficulties in approaching or working under aircraft
2) Jungle penetrator inadvertently released upon ground contact
3) Blood sample (1 subject 75 ft level)
4) No noise or exhaust heat problems

HH-53
(25 ft to 200 ft)

1) Aircraft more difficult to approach at 50 and 75 ft level than at the 10 ft and 25 ft level
2) No problem while directly under aircraft at any level
3) Penetrator inadvertently released upon ground contact
4) Blood sample (1 subject 75 ft level)
5) No noise or exhaust heat problems

XC-142A
(50 ft to 200 ft)

1) More difficult to work and approach than HH-3 or HH-53
2) Body approx 40° angle when approaching aircraft at low hover height
3) Gusty side loadings at 80 to 125 ft. Very small calm area directly under aircraft
4) Would be extremely difficult to keep footing on slippery surface
5) Air sample tanks opened at 200, 150, and 100 ft levels
6) Blood sample (1 subject at 100 ft)
7) Blood sample (1 subject cumulative for all levels)
8) No noise or exhaust heat problems
9) Found it easier to "back out" from under aircraft so as not to lose footing

SUBJECTIVE COMMENTS

Forest Site (Range 22)

(Trees in area up to 48" in circumference, approx 65 ft high)

HH-3 (75 ft to 200 ft)

1) No problems in movement at all altitudes

2) Small branches, twigs broken off by downwash

3) 125 ft dummy pickup made with no difficulties

HH-53 (80 ft to 200 ft)

1) No major problems in movement at all altitudes

2) Branches 6" in circumference broken off by downwash

3) Pickup cable wrapped around tree. Hoist operator unable to raise or lower penetrator. Tree had to be chopped down and cable cleared in order to continue tests (cause - circular lashing of trees)

4) Anemometer propeller shattered by tree limb

5) Forest penetrator disengaged from cable on ground contact

6) One pickup made at 150 ft and one pickup made at 125 ft levels

XC-142A (100 ft to 200 ft)

1) Gusty side loadings, tolerable but difficult to move about and work in area at 100 - 125' level

2) Many branches broken off at test site. Examples:
   a) 3 pine branches 9", 10", 11 ½" in circumference lieing 5 ft from dummy pickup site, bay tree branch 15½" in circumference 5 ft from dummy
   b) Top 25 ft of 60 ft tree broke off 90 ft from dummy
   c) 3 pine trees 21" in circumference bent over within 7 ft of ground 50 ft from dummy
   d) 1 broken branch 10" in circumference struck subject in head. No injury.
   e) 1 tree uprooted 50 ft from ground zero
   f) secondary growth fairly well cleaned out at ground zero

3) Could feel heat from engine exhaust at one point. No problem

4) Pickup made at 125' level. Dummy very stable. No lashing of trees was observed

5) Would have been easier if pickup was made with aircraft headed into wind

6) Recommend minimum pickup altitude of 125 ft until further testing be done

7) Best approach for all altitudes was along wings

8) Forest penetrator inadvertently released on ground contact

The XC-142A also started its hovering at two-hundred feet and worked down collecting data at each twenty-five foot increment. The downwash from the XC-142A also caused the trees to thrash about violently and broke off bay tree limbs up to 5 inches in diameter. Based on observations at the time it was decided not to hover the XC-142A below 125 ft., but the aircraft drifted to as low as 100 ft. in hover. The live test subjects in the trees under the aircraft were consulted with regard to the altitude to be used for the dummy pickup. Based on their recommendation, the XC-142 was hovered at one-hundred twenty-five feet where the dummy pickup was made without trouble. Two other trees, about four inches in diameter, were given a permanent set by the XC-142A downwash similar to those bent over by the HH-53B downwash.

The HH-3E forest test was flown the next morning, 25 August. The test procedure was the same as for the other aircraft with the hovering being performed down to tree top level. The effects of the HH-3E downwash were mild compared to the HH-53B and XC-142A and the dummy pickup was made without trouble.

Following the forest test, each aircraft was flown back to Eglin Auxiliary Field No. 4 where the Flight Dynamics Laboratory instrumentation van had been left to record data on the hoist cable hook as it was lifted beneath the aircraft. For this portion of the test, two microphones and a pressure transducer were attached to the hoist cable hook and lifted to within twenty-five feet of each aircraft while it hovered at 100 feet.

The primary objective of these tests was to perform a comparative evaluation of three V/STOL aircraft in a common environment. Within this frame of reference, the tests are considered to have been successful. Based on the results of this test and previous accomplishments with tilt wing aircraft, their use for rescue purposes is considered to be feasible. It might be necessary or desirable to develop special operational techniques or protective personal equipment for use in various special or extreme climates and environments such as arctic cold, alkali deserts, tropical rain forests, etc. This fact is not detrimental to the use of this type of aircraft for rescue, however, since all other systems also make the use of various items of personal equipment and the development of operational techniques peculiar to the system and the mission.

The limitations of the instrumentation, facilities, and precise positioning capability of the test aircraft prevent use of

the data as absolute values. However, the data collected are considered useful in establishing trends for comparison with theory and for a comparative evaluation of the three aircraft within the limited environment of the test program.

One of the important results of the test was to point up the need for the development of special instrumentation and facilities for future testing of this nature.

Air flow under both the helicopters and the XC-142A was much more turbulent than anticipated. The large size of the anemometers caused poor response and inaccurate data for those anemometers located in the most turbulent area directly under the aircraft. Anemometer data was discarded for positions 3, 4, 5, 6, and 9 shown in Figure 5. This resulted in having no valid measured velocity directly under the aircraft. Based on review of the records, other data were considered acceptable except for isolated cases where data points were discarded for causes such as known poor aircraft positioning. The faired curves based on acceptable data are shown in Figure 23. Two curves are shown for the XC-142A. The one curve shows flow measured along the fuselage axis. Higher velocities are considered to be due to flow reinforcement from the propeller locations on each side of the fuselage. The lower curve shows flow measurement at positions near the wing tip which are comparable in value to velocities measured for the HH-53B at heights above 100 ft. Below 100 ft., the velocities measured under the XC-142A increase rapidly. The curves compare the horizontal flow velocities around the periphery of the primary flow field. The primary anemometer positions (1, 2, 7, 8, and 11) used are shown on Figure 19. Pressure rakes were also used to measure velocities at 30, 60 and 90 ft. from ground zero on the north and west axes.

Data from the rakes correlated very well with anemometer data at comparable conditions for the HH-3 and the XC-142A. The data did not correlate for the HH-53B. The velocities measured with the pressure rakes are consistently higher for the HH-53B than data measured with the comparable anemometer. This problem is discussed in the data reduction section.

Some effort was made to compare test results with downwash theory. No correlation can be expected in the turbulent area directly under the aircraft but reasonable agreement with theory is obtained in the data from the more remote instrumentation (See Figs. 20a, 21a and 22a). The tests show that any criteria, such as limiting dynamic pressure, which might be proposed for future design would have to be largely tempered with flying techniques in a rescue mission and possibly the location of the hatch or winch with respect to the turbulent area under the vehicle.

The microphone data from the fixed instrumentation near the ground indicate large oscillatory pressures in the downwash. However these aerodynamic pressure fluctuations, which were frequently higher in level than the radiated noise in the lower frequency bands, are indeed a part of the physical environment.

The XC-142A aircraft generated the highest sound pressure levels at each hover altitude.

Table I presents maximum sound pressure levels (SPL), downwash velocity and temperature rise under the three aircraft. The notes indicate for each aircraft the hover altitude at which the maximum values occurred.

Table I - Ground Instrumentation Test Results

	Sound Pressure Levels				Velocity Knots (5)	Temperature Rise Above Ambient ^{o}F
Aircraft	Overall dB	1/3 Octave dB	Peak Center Frequency Hz	1/3 Octave at 1000 Hz dB		
1	2	3	4	5	6	7
XC-142A	138 (1)	129 (1)	16 (1)	116 (1)	60 (1)	12.6 (1)
HH-53B	123 (2)	117 (2)	16 (2)	93 (2)	40 (3)	18.0 (4)
HH-3E	121.5 (3)	116 (3)	12.5 (3)	96.5 (3)	29.5 (3)	6.3 (4)

NOTES: (1) At 50 foot hover altitude: lowest test altitude for the XC-142
(2) At 75 foot hover altitude
(3) At 25 foot hover altitude
(4) At 10 foot hover altitude
(5) Maximum average values. Peak XC-142A velocity on anemometer was 82 knots.

The maximum overall SPL ranged from 121.5 dB to 138dB as shown in the second column. These overall SPLs were principally established by the levels (column 3) in the low frequency 1/3 octave bands (column 4). Sound Pressure levels in column 5 are those measured in the 1/3 octave band containing the frequencies around 1000 Hz. These are the frequencies most pertinent to speech communication. The SPLs at these frequencies are greater for the XC-142A than for the helicopters by more than 19 dB.

Table II shows the maximum values of sound pressure levels, dynamic pressures and corresponding downwash velocities which were measured during the instrumented hoist cable reel-in tests.

Table II - Reel-in Test Results

	Sound Pressure Levels				Dynamic Pressure psi	Velocity Knots
Aircraft	Overall dB	Peak 1/3 Octave dB	Peak Center Frequency Hz	1/3 Octave at 1000 Hz dB		
1	2	3	4	5	6	7
XC-142A	125.5[2]	120[2]	315[2]	111[2]	0.027[3]	33.9[3]
HH-53B	118.5[1]	111.5[1]	12.5-16[1]	95[1]	0.058[2]	49.7[2]
HH-3E	112.5[1]	107[1]	16[1]	95[1]	0.030[3]	35.7[3]

NOTES: (1) At 25 feet below aircraft
(2) At 50 feet below aircraft
(3) At 75 feet below aircraft

The vertical component of the downwash velocity obtained from reel-in tests beneath the HH-3E was approximately 28 percent lower than the velocity beneath the HH-53B. For the XC-142A, the measurements were made forward of the flow field due to the location of the bailout hatch used for recovery. The maximum measured vertical component of the downwash velocity beneath the XC-142A was 32 percent lower than the velocity beneath the HH-53B.

The maximum overall sound pressure levels (column 2) were less than those measured in the ground measuring plane since here, radiated sound pressures only were measured, and the large ground turbulence effects are absent. For the XC-142A the most important source was the jet noise as indicated by the spectrum peak at 315 Hz (column 4). Correspondingly, the primary noise source for each helicopter was the rotor, hence the spectra peaked at the lower rotor blade-passage frequencies. The maximum measured dynamic pressures are shown in column 6 and the corresponding velocities in column 7. These velocities are somewhat higher for the helicopters than the horizontal velocities measured by the anemometers four feet above the ground.

CONCLUSIONS AND RECOMMENDATIONS

3.0

3.1 Despite the limitations imposed on the downwash velocity data by instrumentation limitations and inaccuracies in aircraft positioning, it can be concluded that while the data will not give precise values, it can be used to obtain a good comparison of the relative strength of the downwash for the three aircraft. Also, while the data is not of the type to be used in establishing rescue vehicle downwash design criteria since no human tolerance limits were investigated, it can be used as a design tool to determine the approximate strength of the downwash.

The calculated downwash data agree favorably with the experimental data at the lower fuselage heights, but tend to diverge as altitude increases. This discrepancy is probably caused by insufficient simulation in the calculation method of viscous effects present in the highly turbulent flow field.

The development of theoretical procedures to accurately define the flow field beneath a hovering air vehicle will be a lengthy and involved process. It is recommended that the emphasis be placed on empirical methods developed from a comprehensive series of experimental tests. A starting point could be better definition of the downwash field in the area where the flow has impinged upon the ground and turned horizontal.

3.2 Based on dummy pickups previously made at AFFTC and the simulated rescues made from the forested area at Eglin AFB, it is concluded that safe pickups can be made from clear and forested sites with an aircraft with a moderate disc loading such as that of the XC-142A (41.5 lbs/ft^2). At present, this has been shown only for daylight, summer temperature conditions and hover heights of 125 ft or greater.

3.3 To avoid high downwash velocity on the ground and excessive disturbance and damage to the forest cover, the XC-142A must hover at a greater height above the trees than the lower disc loading helicopters. The recommended height above ground for the simulated forest condition was 125 feet. The trees were approximately 70 feet high. The lowest hover height for the HH-53B was 75 ft or tree top level. Vegetation other than pine trees may impose other restrictions on either of these aircraft.

3.4 The effects of downwash are considerably greater for the HH-53B than for the HH-3 helicopter. The increase is partially due to the increased disc loading from 5.51 to 8.55 lbs/ft^2. Also, the total mass of air moved is greatly increased due to the higher gross weight of the HH-53B at 35,000 lbs compared to 16,650 for the HH-3.

3.5 The best approach to the XC-142A aircraft (to minimize air flow effects on the man) is under the wing as previously reported at AFFTC. A region of reinforced flow exists along the fuselage axes causing higher velocity horizontal flow. A region of relatively low velocity turbulent flow exists directly under the aircraft. Men can work in this region with the aircraft hovering at 75 ft. height.

3.6 The ambient noise level of the XC-142A does not appear to be high enough to cause permanent ear damage during the normally short period of exposure. Adequate protection would be provided by the standard Air Force helmet. Some aural communication is possible under the aircraft but is difficult.

3.7 The forest penetrator should be improved for the rescue operation. The forest penetrator used for the simulated pickups disconnected from the hoist cable several times during the test when the penetrator touched the ground. Accidental release of the penetrator from the snap-on hoist cable could lead to an accident or possibly prevent the survivor from being able to locate the penetrator or lift line after inadvertant disengagement.

3.8 A survey of existing velocity measurement methods and equipment should be made and a study should be conducted to determine appropriate techniques and recommended test equipment for future downwash velocity measurement.

3.9 It is concluded that no toxic hazard exists from either CO or the oxides of nitrogen for personnel working or rescued under the XC-142A.

3.10 The following personnel protection should be provided and procedures followed for rescue with either the HH-53B or the tilt wing concept:

a. The minimum required personnel protective garments include the standard Air Force helmet (or equivalent) with visor intact and full down and the standard flight suit (or equivalent).

b. Gloves, flight boots, and flight jacket are recommended and will generally be essential for cold weather operations.

c. Slippery, uneven terrain, presence of briars and vine growth, dusty, debris littered areas, and night time conditions will increase the difficulty and danger of rescue attempt and should be avoided whenever possible.

d. When approaching the central zone of relative calm, advance slowly with a wide stance, prepared to counteract lateral gusts. When leaving this area, the best procedure is to walk backwards, facing the aircraft.

e. The head and especially the eyes should be protected from the dirt and debris being dislodged and blown about by the downwash.

3.11 The spectrum of operational environments within which V/STOL-type rescue aircraft might eventually be used covers a much wider range of terrain, climatic, and lighting conditions than those tested in this program. Moreover, the subjects were not debilitated by fatigue, injury, shock, or panic. Recommend additional testing be accomplished under a spectrum of operationally realistic conditions.

4.0 DESCRIPTION OF TEST EQUIPMENT AND SITES

4.1 Test Aircraft

The XC-142A aircraft was used as a relatively high disc loading aircraft for comparison with the low disc loading helicopters. The XC-142A is a tilt-wing V/STOL aircraft powered by four General Electric T64-GE-1 (3080 SHP) wing mounted turboshaft engines driving four tractor propellers and a tail propeller through an interconnecting gear and shaft train. (See Figure 1). The XC-142A aircraft S/N 62-25924 used for this test was standard except for the rescue hoist installation over the forward bailout hatch and external cameras mounted for the tests. The amount of fuel available for hover tests was dictated by the ambient temperature at the time of test and was based upon having a minimum thrust-to-weight ratio of 1.17 to provide for a safe recovery in the event of an engine failure. The average gross weight of the aircraft for the hover tests (downwash and rescue) was 31,825 lbs. The four propellers are 15 ft 7.5 in diameter. Disc loading at the gross weight flown was 41.5 lbs/ft^2.

The HH-53B helicopter is the new rescue helicopter now entering service to complement the HH-3 helicopters which are in use as combat recovery aircraft by the Air Force. The test HH-53B (Figure 2) used was standard except that some of the combat equipment was not aboard the aircraft. The helicopter has a single main rotor of 72 ft 3 in. diameter and a tail rotor for directional control. Aircraft average gross weight for the test was 35,000 lbs. For these conditions, the disc loading was 8.55 lbs/ft^2.

The HH-3E helicopter (Figure 3) used for the test was standard except for removal of combat equipment. The single main rotor is 62 ft. in diameter. Gross weight for the test was 16,650 lbs. Disc loading was 5.51 lbs/ft^2 for these conditions.

4.2 Downwash Characteristics Measurement Site

The test was conducted over an inactive runway which provided terrain which was open, flat and clean with a prepared surface. The area was sufficiently away from buildings, trees, rocks, etc., so that no obstacle was present to distort the flow field. A slight crown existed along the center of the runway. The test site with instrumentation mounts, is shown in Figure 4.

4.3 Downwash Instrumentation

Instrumentation of the downwash site was located in accordance with Figure 5. Anemometers were mounted at a uniform height four feet above the site floor. Other sensors (temperature, noise, and pressure) were also mounted at uniform heights. An anemometer, mount and other instrumentation are shown in Figures 6 and 7. Primary consideration was given to the anemometers, which were mounted to rotate on a horizontal axis and in a plane through ground zero. Pressure rakes of the type shown in Figure 8 were located as shown in Figure 5 on a mutually non-distorting basis. All instrumentation was remote indicating. All except the rake pressures and wind velocities were recorded simultaneously in the Flight Dynamics Laboratory Van provided for this purpose. (Figure 9) Rake pressures and anemometer readings were recorded in a second van provided by the contractor.

Nytron LD-1000 amplifiers located about three feet from the microphones were used to amplify microphone outputs to provide low-impedance, high-level signals for transmission to the tape recorder. Parallel connections were made to the Air Weather Service's anemometer outputs. After attenuation, the anemometer outputs, together with wind vane outputs, were commutated at the rate of 30 samples per second, per channel and recorded on tape. The thermocouple and pressure transducer outputs also were commutated and amplified by a Nytrol LD-1000 amplifier, and then recorded on tape.

Field test instrumentation consisted of (1) a Honeywell 14-channel FM tape recording system, (2) a 12-channel Brown, strip-chart temperature recorder, (3) nine Gulton Model MA 299501 microphones equipped with Bruel and Kjaer (B&K) Model UA0051 nose cones, (4) nine strain-gage type differential pressure transducers (five of these had full scale ranges of ± 1 psi and the remaining two had full scale ranges of ± 7.5 psi), (5) twenty-two iron-constantan thermocouples, ten of which were connected to the tape recorder and twelve to the temperature recorder, (6) nine potentiometer type wind vanes, (7) a variety of signal conditioning equipment and auxiliary instruments.

In addition to the transducers mounted four feet above the runway, one Gulton microphone, one Altec microphone furnished by LTV for comparison purposes, and one ± 1 psi pressure transducer were used for the hoist cable reel-in tests below the three aircraft.

The frequency response of microphone channels was flat from 2 to 10,000 Hz. The pressure transducer frequency response was limited to 15 Hz by Low-pass filters. The anemometer outputs were filtered by an RC network with a time constant of 0.1 second to remove anemometer generator ripple voltage.

4.3.1 Anemometers

Anemometers used in the test program were Seaview Electronics wind direction and speed transmitters, designed to rotate in a horizontal plane and measure natural wind velocities. The anemometers were modified and mountings were such as to permit rotation in a vertical plane. To prevent complete rotation during the test cycle, the anemometers were restrained to plus or minus approximately 100 degrees directional motion from the vertical position. All anemometers were alligned so their plane of rotation on the pivot passed through the center of the test site. Data from the anemometers were recorded on strip charts at a remote location by USAF Weather Bureau personnel. Chart speeds used for recording downwash velocity were as follows: six inches per hour for the XC-142A and HH-3E and three inches per hour for the HH-53B. The instruments were calibrated before the test program began, but some destruction was encountered during the XC-142A program which prevented calibration at the completion of the test program.

4.3.2 Sound Measurement

Each Gulton microphone was calibrated after installation by a General Radio Type 1552-B sound level calibrator. Microphone amplifier gains were adjusted to give 0.1 volt rms output with 120 dB sound level input. With this calibration level, full scale measurement capability was about 140 dB. One exception to this calibration procedure was for the reel-in test under the HH-3E where the microphone amplifier gain was adjusted to give 0.335 volts for 120 dB to correspond with the sensitivity of an Altec microphone furnished by LTV for comparison purposes.

4.3.3 Temperature Measurement

The ten thermocouples that were recorded on tape were connected through 100 to 150 feet of thermocouple wire to an ice bath where junctions were made from iron-constantan to the copper cables.

4.3.4 Data Reduction Procedure

Magnetic tapes recorded at the test site were played back in the Laboratory on a Honeywell Model 3170 tape record/reproduce system. Overall and one-third octave band analyses of sound data were performed over the frequency range of 12.5 to 10,000 Hz using B&K type 2111 Audio Frequency Spectrometers and B&K Type 2305 Level Recorders. Selected analyses also were performed using 2 cps, 10 cps and octave bands. An averaging time of 5.5 seconds was used during these analyses.

Commutated pressure, temperature, anemometer, and wind vane data were decommutated on a Ralph M. Parsons Model 5254 decommutation system. The decommutated data were recorded on a direct writing oscillograph.

The weather bureau strip chart recordings of wind velocity were examined to determine which anemometers appeared to be providing accurate data. Reference was made to the flight schedule for location of the aircraft over the instrumentation during the taking of data.

Anemometers 3, 4, 5, 6, and 9 were eliminated from consideration because of their location in highly turbulent flow areas. Specific test points were eliminated if strip chart readings indicated excessive directional fluctuations or the aircraft was incorrectly positioned over the instrumentation. All data considered acceptable were recorded on anemometers which were in a region of flow essentially parrallel to the ground. Data points were obtained from the strip charts by locating a position on the recording corresponding timewise to test points listed on the flight schedule. Maximum velocity data were recorded for each altitude and vehicle heading.

4.4 Forest Rescue Site

The site selected for the forest hover tests was chosen to provide a good balance between safety of aircraft operation and realism of forest cover available on the Eglin AFB complex. Trees in the area were largely pine ranging to over 15 in. in diameter. Height of the trees ranged up to approximately 70 ft. Density of the forest cover can be seen from Figures 13, 14, and 15. The relatively clear areas provided easy ground access to the more dense area used for the ground zero point.

4.5 Forest Instrumentation

Instrumentation of the forest site was attempted on a meager basis. Three anemometers, two pressure rakes and a vertical looking camera were mounted at and near ground zero. Five microphones were located at the forest site. One was located at ground zero. Additional microphones were located at positions 60 ft north, east, and south of ground zero. One microphone was located 80 ft west of ground zero. Altec microphones and wind screens supplied by Ling Temco Vought were used in the forest area. During sound level measurement tests, while reeling instrumentation into the aircraft, a comparison of the Air Force and Contractor supplied microphones was made. Excellent agreement was obtained for all conditions compared.

5.0 TEST PROCEDURES AND RESULTS

5.1 Downwash Measurement Flights

Every attempt was made to conduct the hover flights over the instrumented site under zero wind conditions. The magnitude and direction of the prevailing winds were measured prior to the arrival of the test aircraft at the site. Recordings were made at ground level and also at the hover heights of 25 and 50 ft. Winds were light and variable for the tests over the instrumented site. During the helicopter tests, winds were out of the north from 310 to 360° and did not exceed four knots during the test. During the XC-142A tests, winds were generally out of the east and ranged from two to five knots. Conditions were considered nearly ideal for the tests. To provide comparable data between the HH-3E, HH-53B, and XC-142A aircraft, all aircraft were hovered at the clean area test site heading due north (0°) over the hover reference point regardless of wind direction. (See Figure 5). All aircraft were also hovered at the test site in a northeast (45°) heading over the reference point. The positions of the aircraft above the site were with the center of the propulsive device directly above the hover reference point. The center of the propulsive device is defined as the center of the rotor hub for the helicopters, and the intersection of the XC-142A longitudinal centerline axis with the wing tilt axis.

5.1.1 Positioning of Vehicles Above the Terrain

The helicopters were flown at eight different heights above the ground. These heights were 10, 25 50, 75, 100, 125, 150, and 200 ft above the ground. The XC-142A aircraft test points ranged from 200 down to 50 ft. "Height Above the Terrain" is defined as the vertical clearance between the terrain at ground zero in Figure 5 and the bottom of the fuselage.

The positioning of the aircraft over the test area was at first accomplished by lowering the forest penetrator from the vehicle to a properly located circle on the ground. By noting the length of marked cable unreeled from the winch the aircraft had a good height indicator. A method was then devised for positioning of the aircraft by having the pilot observe visual signals for his lateral position while aural instructions were relayed via UHF radio for fore and aft positioning. The pilot was in this manner, able to position the aircraft within a few feet of the desired position in the sky for all the test points flown.

A transit was also used during the XC-142A tests to insure that the radar altimeter was giving consistently accurate results.

5.1.2 Results of the Velocity Measurements

5.1.2.1 General

Eleven anemometers of the type described above were arranged in the pattern shown in Figure 5. The object of this portion of the testing was to determine the velocity of the downwash under and close to the vehicles at a height above the ground equal to that of a human's chest (four feet). Velocities recorded at the anemometers are not necessarily the maximum velocities in that region since theory predicts that the velocity varies with height above the ground.

The large size of the anemometers and their slow response time made it impossible for them to measure the peak transient velocities associated with the turbulent flow. This applies to the minimum as well as the maximum. Also the chart recording speed was inadvertently set at three inches per hour during the HH-53B test program which made anemometer data reduction somewhat difficult and could possibly have led to errors.

The turbulent flow at anemometer positions 3, 4, 5, 6, and 9 caused the data taken at those points to be unacceptable and it was discarded. Additional velocity data taken for each aircraft were discarded because of the known poor positioning of the aircraft.

All anemometers were aligned so their plane of rotation on the pivot passed through the center of the test site. This was the correct alignment for all test points with the exception of the points when the XC-142A was at 45° heading. Since the anemometers could not be turned during the testing, the data recorded when the XC-142A was at a 45° heading was considered questionable and was not used. The downwash velocity data obtained from the selected anemometers are considered to be sufficiently valid to be used for comparison purposes.

Pressure rakes were located as shown on Figure 5. Six rakes were used, positioned at 30, 60, and 90 ft from ground zero on the North and West axes. Seven probes were mounted on each rake to measure horizontal velocity. The lowest probe was six inches above ground. Six probes were spaced at one foot intervals from one foot to six foot heights. One probe was located on top of the rake directed to measure

vertical velocity. Dynamic pressures measured were converted to wind speed. Wind direction was assumed to be radially out from the ground zero point under the aircraft. As discussed previously, the flow direction was questionable for the XC-142A hovering with the 45° or northeast heading. Therefore, these data were not used for comparison purposes.

Aircraft parameters which affected the data taken are as follows:

(a) The aircraft weights for the test were limited by the free air temperature and altitude at which hover was possible. A margin between maximum hover weight and test hover weight was allowed for safety. The average hover weight of the HH-3E was 16,650 lbs at a mid C.G. The average hover weight of the HH-53B was 35,000 lbs at an aft C. G. The weight of the XC-142A was 31,825 lbs at a forward C. G.

(b) The disc area was important for two reasons. First, it determined the disc loading for the given aircraft gross weights, and second, the position of the anemometers relative to the edge of the disc area determined the region in which velocities were measured. The average disc loadings are 5.51, 8.55 and 41.5 lb/square ft on the HH-3E, HH-53B and XC-142A, respectively. Figure 19 shows the position of the anemometers relative to the disc areas of the air vehicles. It should be noted that during these tests, the XC-142A was at a forward C. G., and therefore the tail rotor did not affect the downwash data recorded.

(c) While the data were being recorded, the pilots attempted to position the aircraft directly over ground zero. This was not always possible and therefore data were recorded along with the notation of the actual position of the aircraft. This will be discussed further below.

5.1.2.2 Velocity Data Reduction and Results

a. Anemometers

The data reduction process was initiated by eliminating all data which (1) were in so turbulent a region that it was impossible to determine a value of direction or velocity, or (2) were in error due to anemometer propeller inflow angles other than 90°, caused by erroneous aircraft positioning. By this method it was possible to eliminate much inaccurate data. It should be noted that all data considered useful were recorded at anemometers which were in a region of essentially horizontal flow.

(1) HH-3E - Analysis of the strip charts showed that the HH-3E was positioned well laterally during the tests, but varied considerably in fore and aft position. During these tests the pilot visually positioned the aircraft in a lateral direction and the accuracy in doing this appeared very good. The pilot, however, had to position the aircraft longitudinally by instructions from a ground controller, and while this worked quite well at lower wheel heights, the pilot was unable to position the aircraft accurately at high wheel heights.

Although the exact position at each test point could not be determined, it was possible to find which anemometers were outside of the rotor disc area. For each test point, data were used only from the anemometers which were between one and two rotor radii from the center of thrust. For these positions, the velocity should be constant for a given wheel height, at the height of the anemometers above the ground. These data are plotted in Figure 20a. No data were plotted at the intended 10 ft fuselage height as actual height above the ground was uncertain.

(2) HH-53B - An analysis similar to that used for the HH-3E was attempted on the HH-53B, however, the chart speed was erroneously set lower during the HH-53B tests and it appears to be impossible to determine air vehicle position using the charts. Therefore, the data from the flight information sheets was used.

A review of the strip charts showed anemometers 1, 7, 8, and 11 were the only ones not adversely affected by excessive oscillation. The data from these anemometers are plotted in Figure 21a. As mentioned above, aircraft position appears to be better laterally than longitudinally, and since the longitudinal position is unknown, the data from anemometer 11 would be the more accurate and are the more heavily weighted data used to determine the curve fairing.

(3) XC-142A - The data used to determine the downwash characteristics of the XC-142A are from anemometers 1, 2, 7, 8, and 11. These data show the velocity at two places. The first is under the fuselage centerline (anemometers 1, 2, 7, and 8) and the second is immediately adjacent to the wing tip (anemometer 11). The data for the XC-142A are plotted in Figure 22a. The one curve shows higher velocity values due to reinforcement of the airflow along the fuselage center line from the combined propeller flows. The other curve is the flow measured at the wing tip of the XC-142A.

b. Pressure Rakes

The data from the pressure rakes were recorded as total pressure. Static pressure was recorded at a remote location and subtracted from the total pressure to obtain dynamic pressure. Each probe of each rake was sampled once every ten seconds. This gave approximately three seconds of data for each probe for each test point. The probes had previously been tested and it was found that two tenths of a second elapsed from valve opening to pressure stabilization. Therefore, no data from this portion of each sampling were used.

The pressure data was converted to velocity data and initially the data from the probes four feet above the ground were investigated to determine: (1) if the rakes thirty feet from the center agreed with the anemometers, and (2) what the velocity decay with distance from the center was.

(1) HH-3E - As with the anemometers much scatter was present and therefore only the maximum values were used. The resulting values are plotted on Figure 20b. It is immediately apparent that, despite the large amount of scatter the rake data agree well with the anemometer data. The relatively larger amount of scatter appears reasonable when it is remembered that the probes have a much shorter response time and would record the transient velocities better than the anemometers. It is also apparent from Figure 20b that the change of velocity with distance from the aircraft is lost in the scatter.

(2) HH-53B - Figure 21b shows the maximum velocities recorded at the four foot probe. The anemometer data fall below the mean of the pressure data at every hover height.

(3) XC-142A - Figure 22b shows the data which were recorded at the four foot high pressure probes along the longitudinal axis of the XC-142A. The data show very little scatter and excellent agreement with the anemometer data. The data taken along the lateral axis contained so much scatter that they were useless and therefore are not presented. Multi-rotor effects could account for some of this scatter.

c. Results

Figure 23 shows a comparison of the measured downwash velocities. It should be noted that the velocity measured beneath the wing tip of the XC-142A was slightly less than that measured in the symmetrical field produced by the HH-53B for hover altitudes above 100 feet. The wind velocities in the direction of the fuselage center line under the XC-142A were considerably higher than the velocities under the helicopters.

The final step in reducing the data was to determine if the data for the three air vehicles show correlation when non-dimensionalized. The format used was H/D vs q_s/D.L.; where H is the prop/rotor height above the ground D is the prop/rotor diameter, q_s is the dynamic pressure based on the measured downwash velocity, and D. L. is the disc loading. A single propeller diameter was used to non-dimensionalize the XC-142 data. The non-dimensionalized data are shown in Figure 24.

Calculation of the downwash velocity component at a specified radial distance from the rotor center of rotation at various height/diameter values has been accomplished using the technique described in AFAPL report TR-66-90, "An Analytical Method of Determining General Down-Wash Flow Field Parameters for V/STOL Aircraft" by David J. Hohler. Data were generated for the HH-3E and HH-53B under atmospheric conditions compatible with the experimental studies conducted at Eglin AFB. Two downwash data points were calculated for an XC-142 propeller acting independently. These data are shown for comparison on Figures 20a, 21a and 22a.

Error is estimated to be less than 20% for rotor and propeller downwash calculations. Conservative results are produced, especially at the higher fuselage heights. Experimental data indicate the radial downwash velocity component decays, with increased hover height, much more rapidly than the theoretical results predict. The analytical procedure used is not considered adequate for calculations involving multiple rotors or propellers, hence the XC-142 data is limited to consideration of a single propeller acting independently.

5.1.3 Sound Pressure Levels

Measured one-third octave band and overall noise levels were determined for each microphone location, aircraft heading, and hover altitude for each aircraft. These data measurements represent calibrated signals from an FM tape recorder and do not include corrections for instrumentation noise, microphone directivity, or microphone wind screen effects. The tabulated data were used to determine the arithmetic mean and maximum one-third and overall levels for each aircraft and hover altitude. The average levels were determined by summing the levels corresponding to a given 1/3 octave, aircraft and altitude and dividing by the total number of data points. This was repeated for the overall and each 1/3 octave up to and including 500 Hz. Since the signal to noise ratio was too low in the last three bands (6300, 8000, and 10,000)

they were not considered. The average sound pressure levels obtained are presented in Figures 25 through 32. Each figure contains the averaged levels for the aircraft for which data exist at the given altitude.

Figure 33 presents the average overall sound pressure levels measured below the XC-142A, HH-53B and HH-3E as a function of the hover altitude. These data indicate that except for the 10 foot hover altitude the average overall level under the HH-53B is from approximately 2 to 5 dB greater than the average level under the HH-3E. The average level under the XC-142A ranges from approximately 5 to 20 dB greater than the HH-3E with the smallest difference being at the maximum hover altitude.

The maximum 1/3 and overall levels were obtained by selecting from the tabulated data the maximum level for a given 1/3 octave, aircraft, and hover altitude. This was repeated for the overall and each 1/3 octave up to and including 5000 Hz. The maximum sound pressure levels obtained are presented in Figures 34 through 41. Each figure contains the maximum 1/3 octave band sound pressure levels, measured at any measurement position below the aircraft for the given hover altitude.

Figure 42 presents the maximum overall sound pressure levels measured below the XC-142A, the HH-53B, and HH-3E. This figure indicates that except for the lower hover altitudes the maximum level under the HH-53B ranges from approximately 2 to 7 dB greater than the HH-3E. The maximum level under the XC-142A ranges from 9 to 20 dB greater than the HH-3E. The 9 dB difference is constant above 125 feet whereas below 125 feet the difference increases from 9 dB to approximately 20 dB at 50 feet.

The microphone data from the reel-in tests are presented in Figures 43, 44 and 45. Figure 43 presents the 1/3 octave and overall levels measured 25 feet below the two helicopters while they were hovering at 100 feet. These data show a 3 dB greater overall level under the HH-53B and agree well with the results measured during the 25 feet ground hover tests. Figure 44 presents the spectra measured 50 feet below all three aircraft when the helicopters were hovering at 100 feet and the XC-142A was hovering at approximately 150 feet. These data show that the overall levels of the two helicopters are nearly the same and the XC-142A overall is 10 dB higher. Figure 45 presents the data measured 75 feet below the three aircraft during the same hovering conditions. Under these conditions, the data show the overall level under HH-3E to be 3 dB greater than the HH-53B. The overall level below the XC-142A was 12 dB higher than under the HH-53B. The variation in the overall levels obtained during these reel-in tests are represented pictorially in Figure 46 for all vehicles.

The HH-3E reel-in data were also obtained using a microphone supplied by LTV. The data from the LTV and Air Force microphones are compared in Figures 47, 48, and 49 for 25, 50, and 75 feet below the aircraft. Excellent agreement was obtained for all conditions.

As mentioned above, these microphone data represent calibrated playback data with no correction for instrumentation noise, microphone directivity and microphone wind screen effects.

An attempt was made to eliminate the instrumentation noise by only considering the frequencies below 5000 Hz. Indications are that some data below 5000 Hz still have low signal to noise ratios. These are evidenced in some of the averaged and maximum data by an increase in level at the 5000 Hz and 4000 Hz bands over the levels in the preceding bands. The directivity corrections should be minor for frequencies below 5000 Hz.

Preliminary investigation of the microphone wind screen effects indicate that for the majority of the measurements made, the microphones measured oscillatory pressures in the turbulence existing in the downwash of the vehicles. The turbulent level which was measured was considerably above that which was generated by the microphone wind screens. Figure 50 shows 10 Hz and 2 Hz bandwidth analyses of data taken below the XC-142A and the HH-53B for 50 feet hover altitude. For a random field as one would expect in a turbulent region, the 10 Hz and 2 Hz bandwidth analysis would be similar in shape but separated in level by 7 dB. This is the case for the XC-142A but not for the HH-53B where periodicity is indicated by the difference in the two plots being less than 7 dB.

These XC-142A reel-in data, which were taken outside of the downwash, indicate the spectrum which would have been measured if all measurements were from radiated noise. The peaks in the spectrum for these data can be identified as noise radiated from propeller harmonics and turbine noise as listed in Table I. This radiated noise is masked and attenuated when the microphone is in the downwash.

Although the majority of microphone measurements in the lower 1/3 octave bands for the XC-142A are not radiated noise, they are believed to be a measure of the acoustic or pseudo-acoustic environment which existed below the vehicle and are acceptable for comparative purposes.

The maximum levels occurred under the XC-142A and were in the low frequency range, however, all values were below the threshold of pain given in Figure 7 of Aero Medical Laboratory Report AMRL-TR-66-119.

Preliminary investigation of the levels below the vehicles with respect to speech interference indicate that face to face communication will be difficult under the XC-142A for at least the lower altitudes but should be possible below both helicopters.

5.1.4 Pressure Measurements

The data from the fixed set of pressure pickups were not satisfactory due to problems in decommutating the transducer signals. Therefore the data have been omitted from this report. Based on a limited amount of data which were reduced, it does not appear that the fixed instruments provided acceptable data near the ground due to the high levels of turbulence.

Pressure measurements obtained during the reel-in tests are shown in Figure 51. If it is assumed that changes in static pressure were very small in the region of the downwash at distances of 25 feet or greater below the aircraft then these measurements represent the approximate dynamic pressures associated with the vertical component of the downwash velocity. The corresponding downwash velocities are shown in Figure 51. The maximum velocities indicated beneath the helicopters are within 11 percent of the calculated theoretical values using the Momentum Theorem. It is considered that local flow conditions where the pickup was suspended may have affected the measurements slightly, however, the amount of this effect is presently unknown. The reel-in point on the XC-142A is located approximately five feet forward of the propeller disc region. Therefore, the pressure pickup was not located within the downwash for the XC-142A to the same extent it was for the helicopters. The maximum dynamic pressure measured under the XC-142A was only 0.027 psi. The maximum measured dynamic pressures beneath the HH-53B and HH-3E were 0.058 and 0.030 psi respectively.

5.1.5 Temperature

The temperatures at a typical location, location 4, are plotted in Figure 52. Maximum temperatures measured at any of the eleven locations are plotted in Figure 53. The average ambient temperatures are indicated near the right-hand margin of the two plots so that temperature rise above ambient may be seen. These plots show an insignificant temperature rise under the HH-3E, and small temperature rise below the HH-53B and the XC-142A. For hover at 50 feet altitude, the maximum temperature rise four feet above the surface for the HH-53B and the XC-142A was 6 and 7 centigrade degrees respectively. The maximum temperature rise below the HH-53B while hovering at 10 feet altitude was 10 centigrade degrees.

5.1.6 Medical Evaluation

5.1.6.1 Toxic Hazards Measurement

One aspect of the tests was the evaluation of the environment with respect to potential toxic hazards. For comparative purposes, similar tests were conducted with the H-3 and H-53 helicopter and XC-142A aircraft.

The toxicity studies consisted of three types of determinations: (1) detailed analysis of grab samples of the ambient air obtained on the ground at various hovering altitudes (2) on-site estimates of Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2) in the ground environment, and (3) an estimation of human exposure by measurement of blood carboxyhemoglobin.

Table VI is the blood sample test results and Table VII shows the analysis of the air sample taken under the XC-142A.

Table III - Vehicle Parameters Related to External Environment

VEHICLE TYPE	XC-142A	HH-53B	HH-3E
Main Rotors/Propellers	4	1	1
Nbr. Blades/Rotor	4	6	5
Rotor/Propeller Diameter	15' 7.5"	72' 3"	62' 0"
Approx. Rotor RPM (Hover)	1200	185	203
Tip Speed (Ft/Sec)	980	700	659
Blade Passage Freq (cps)	80	18.5	16.9
Disc Loading (Lt/Ft^2)	41.5	8.55	5.51
Tail Rotors/Propellers	1	1	1
Orientation	Horizontal	Vertical	Vertical
Nrb Blades/Rotor	3	4	5
Rotor Diameter	8' 0"	16' 0"	10' 4"
RPM (Hover)	2400	990	1268
Tip Speed (Ft/Sec)	1005	829	686
Blade Passage Freq (cps)	120	66.0	105.5
Test Gross Wt. (lb)	31,825	35,000	16,650
Engines	T 64-GE-1	T64-GE-3	T 58-GE-1
Shaft Horse Power	3080 Max.	3080 Max.	1250
Turbine RPM	13,600	13,600	19,500
Turbine Freq. (cps)	227	227	325

Table IV - Maximum Ground Environmental Values

Aircraft	Hover Altitude	Sound Pressure Overall dB	Sound Pressure Peak 1/3 Octave dB	Sound Pressure Peak Center Frequency Hz	Sound Pressure 1/3 Octave at 1000 Hz dB	Velocity Knots	Temperature Rise Above ambient °F
XC-142A	50	138	129	16	116	60	12.6
HH-53B	50	120	114	16	95	38	10.8
HH-3E	50	118	112	12.5	95.5	28	2.7
XC-142A	75	134	128	16	107	57	3.6
HH-53B	75	123	117	16	93	38	3.6
HH-3E	75	117	111	125	97.5	25	2.7
XC-142A	100	129.5	122	16	100	52	3.6
HH-53B	100	120.5	115	16	91	37	0
HH-3E	100	115.5	109	63	94	25	2.7

Table V - Environmental Values at Stations Below Aircraft

	Station Below Aircraft	Sound Pressure Level				Dynamic Pressure psi
		Overall dB	Peak 1/3 Octave dB	Peak Center Frequency Hz	1/3 Octave at 1000 Hz dB	
XC-142A	25	-	-	-	-	-
HH-53B	25	118.5	111.5	12.5	95	0.052
HH-3E	25	115.5	107	16	95	0.015
XC-142A	50	125.5	120	315	111	-
HH-53B	50	115	104	12.5	93	0.058
HH-3E	50	115.5	107	16	92.5	0.010
XC-142A	75	123	118	250	110	0.027
HH-53B	75	111	101.5	315	93	0.053
HH-3E	75	114	106	16	90.5	0.030

Table VI

Blood Sample Test Results

	% Carboxyhemoglobin	
Subject	Pre-Exposure	Post-Exposure
#1	ND**	ND
#2	ND	ND
#3*	5	3
#4	ND	ND
#5	4	3

* Subjects #3 and #5 are smokers. Others are non-smokers. A 5% level of carboxyhemoglobin is commonplace for smokers. The post-exposure reduction can be attributed to temporary abstinence from cigarette smoking.

** ND = Not Detectable

Subject #1 - ground test at 75 ft altitude, H-3 helicopter, approx 2 min exposure

Subject #2 - ground test at 75 ft altitude, H-53 helicopter, approx 2.5 min exposure

Subject #3 - winch operator, H-53 helicopter, approx 1 hr hover exposure

Subject #4 - ground test at 100 ft altitude, XC-142A aircraft, approx 1 min exposure

Subject #5 - ground test, XC-142A aircraft, cumulative at all altitudes (200, 175, 125, 100, and 75 ft) approx 4.5 min total exposure

Table VII

Analysis of Environmental Air Samples, XC-142A

Tank No.	Component	Concent. mg/liter
1 - Control	Acetone	0.025
	Ethanol	0.03
	Benzene	0.0002
	Trichlorethylene	0.002
	Toluene	0.006
	C_1-C_2 Chlorofluorocarbons	5.6
	Methane	0.0008
	Carbon Monoxide	0.0005
2 - 200 ft	Benzene	0.001
	Toluene	0.0007
	Methane	0.004
	Carbon Monoxide	0.0002
3 - 100 ft	Acetone	0.01
	Trichlorethylene	0.002
	Toluene	0.002
	Methane	0.006
	Carbon Monoxide	0.001
4 - 75 ft	Acetone	0.001
	Ethanol	0.0008
	Benzene	0.0005
	Toluene	0.002
	Methane	0.002
	Carbon Monoxide	0.0003

Figure 1. XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67.
XC-142 HOVERING OVER FOREST TEST SITE.

Figure 2XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67.
H-53 HOVERING OVER FOREST TEST SITE.

Figure 3. XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67. HH3E HOVERING OVER INSTRUMENTED TEST SITE.

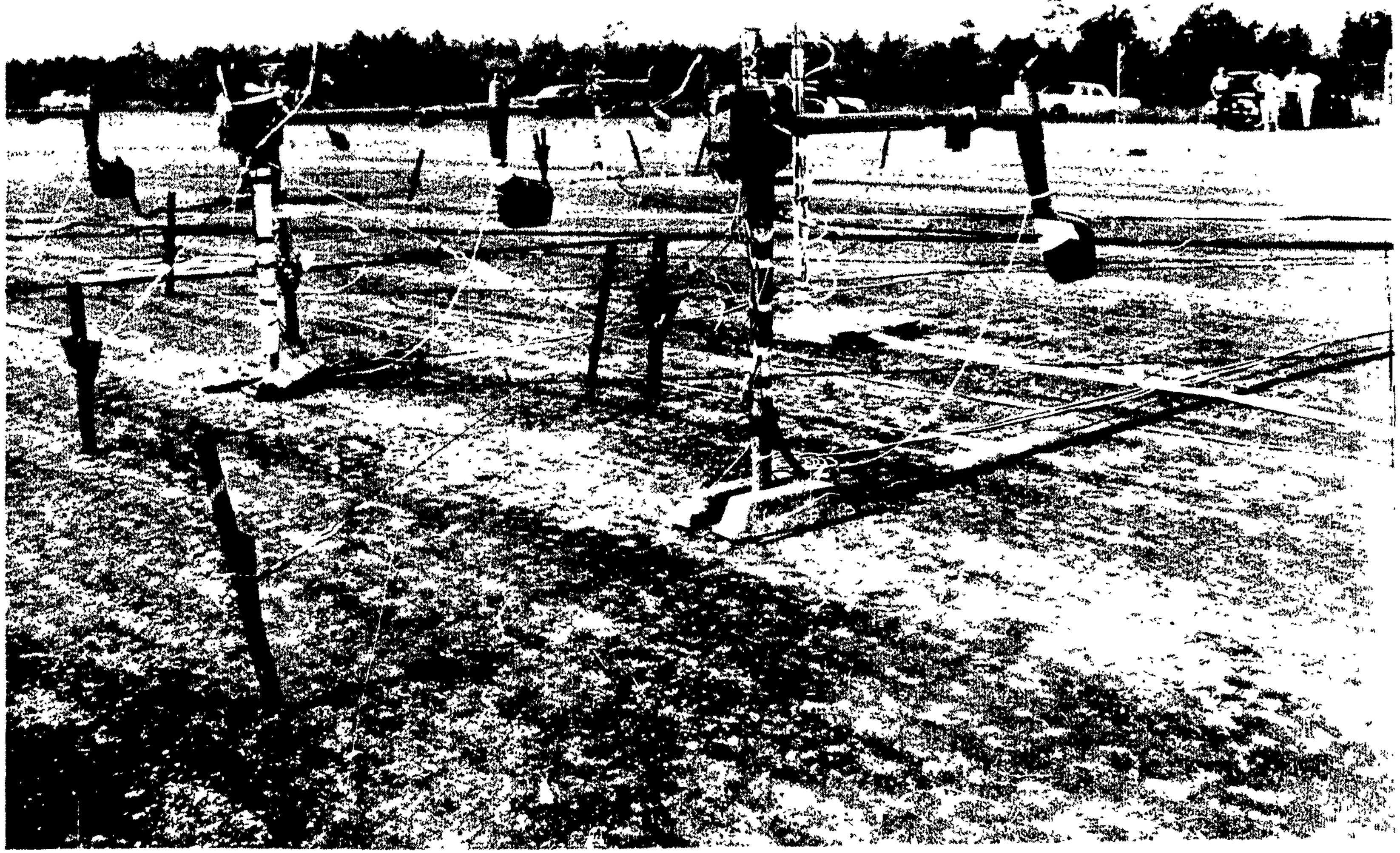


Figure 4. XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67. ANEMOMETERS - INSTRUMENTED TEST SITE.

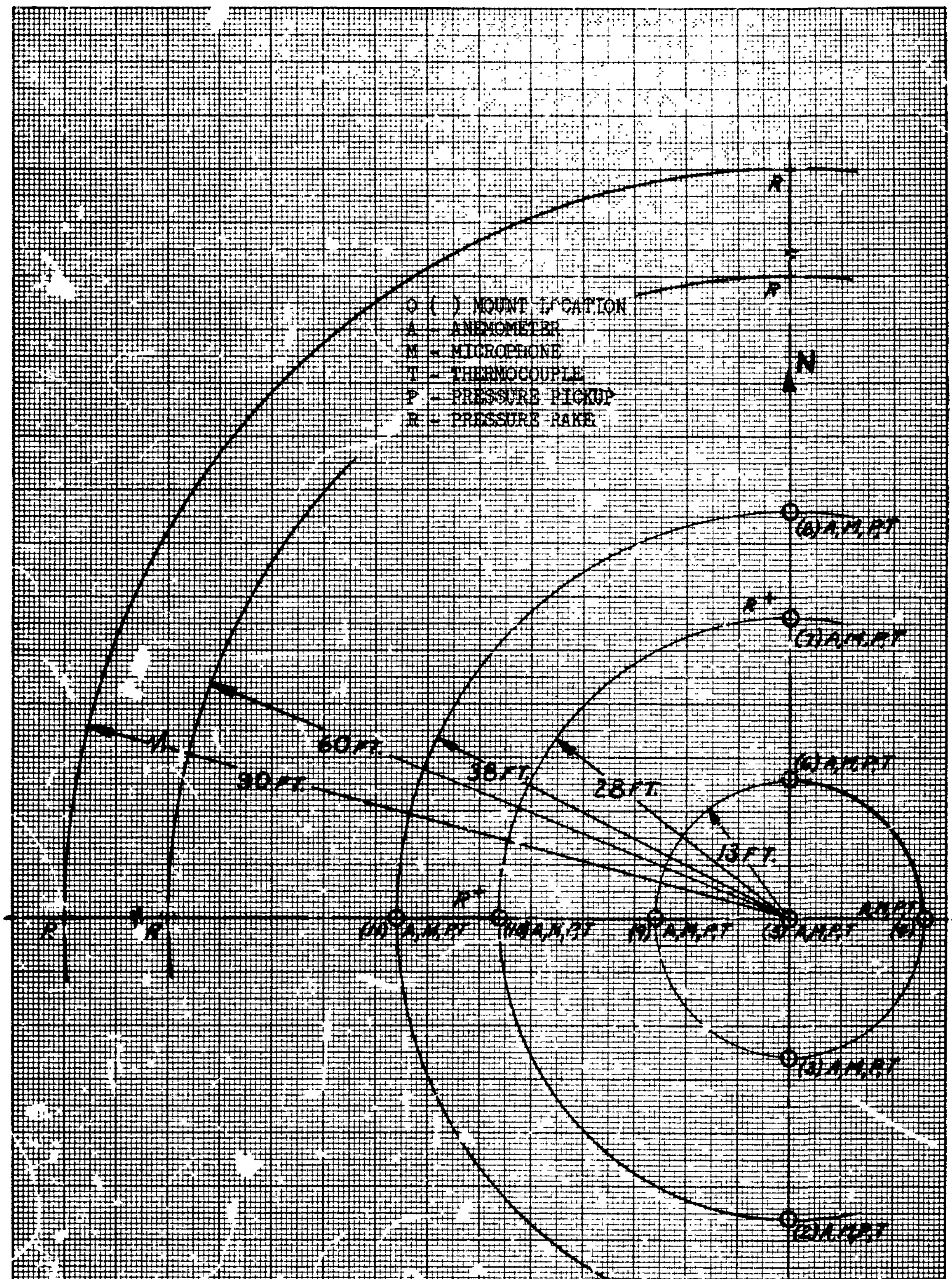


FIG. 5
INSTRUMENT LOCATIONS

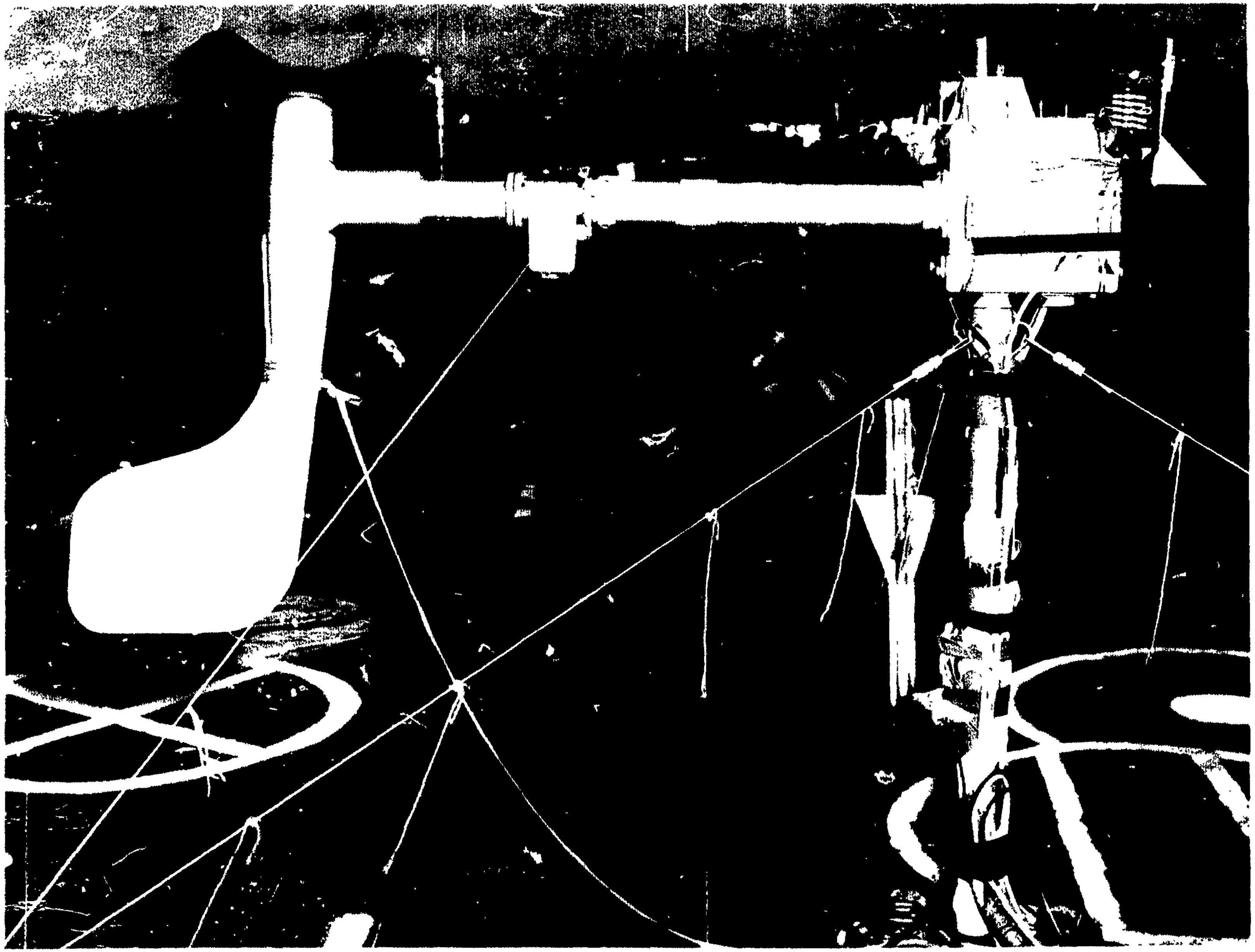
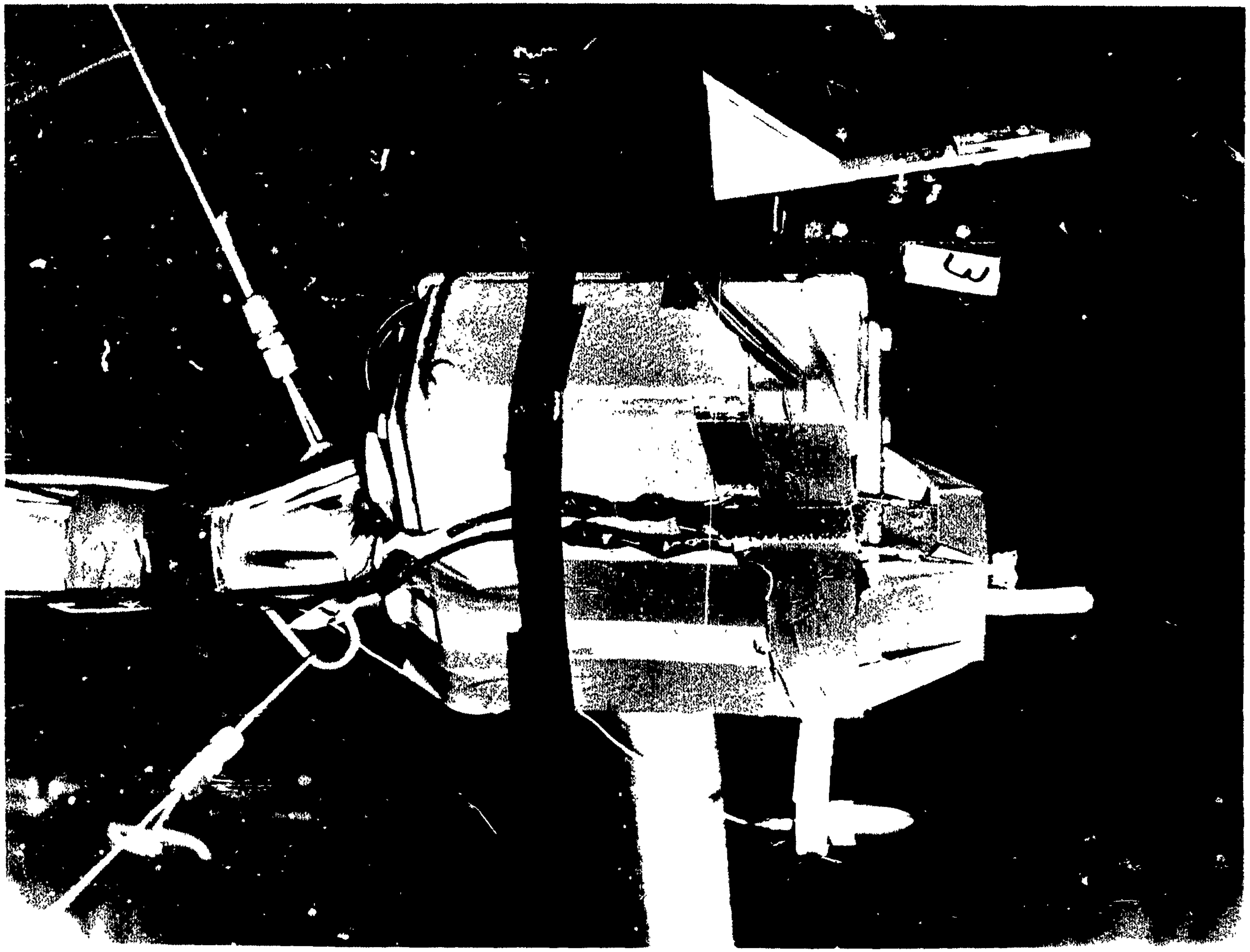


Figure 6. ANEMOMETER AND MOUNT WITH RESTRAINING CORD



[illegible] OTHER INSTRUMENTATION ON ANEMOMETER MOUNT

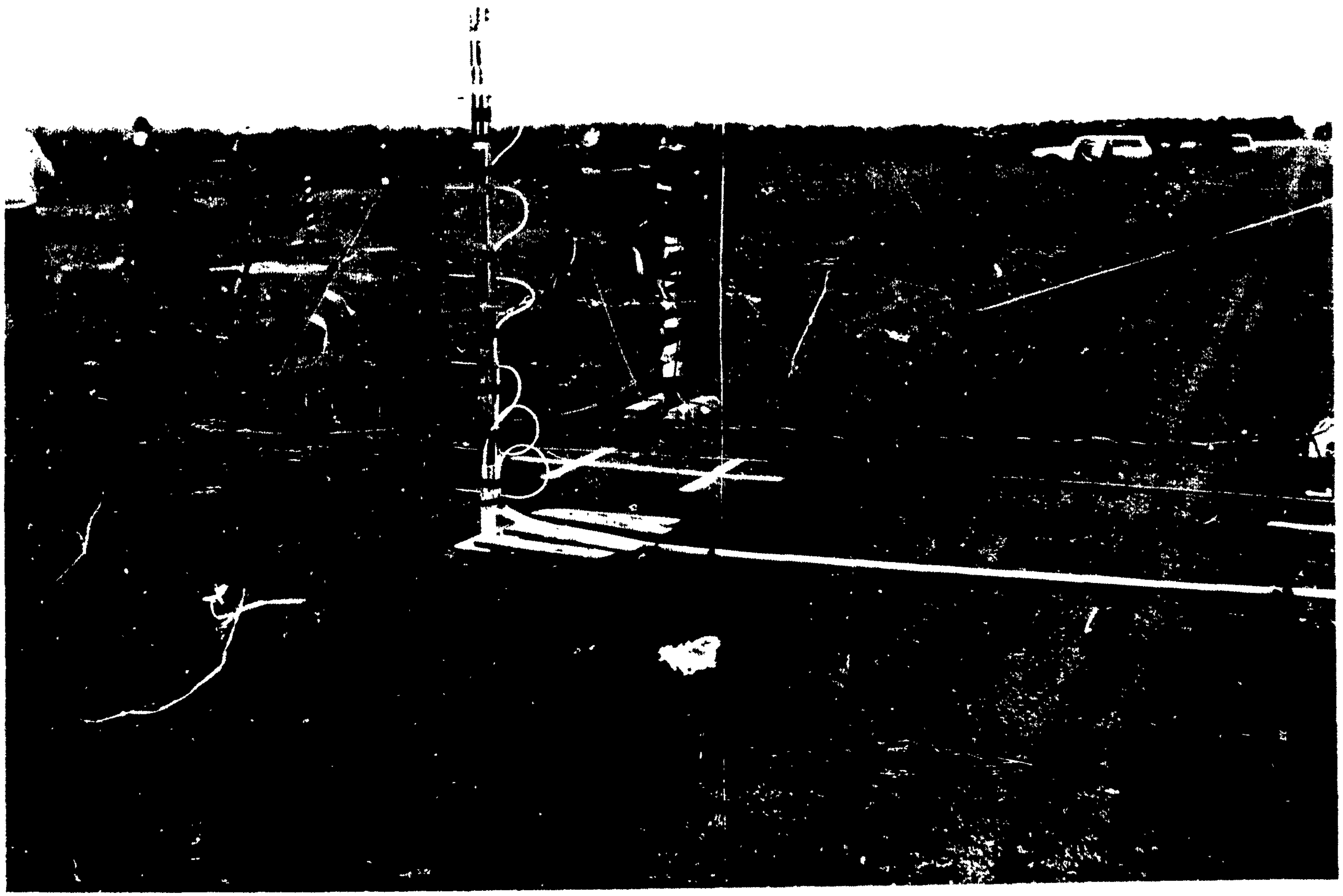


Figure 8. XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67. PRESSURE RAKE INSTALLATION - INSTRUMENTED TEST SITE.

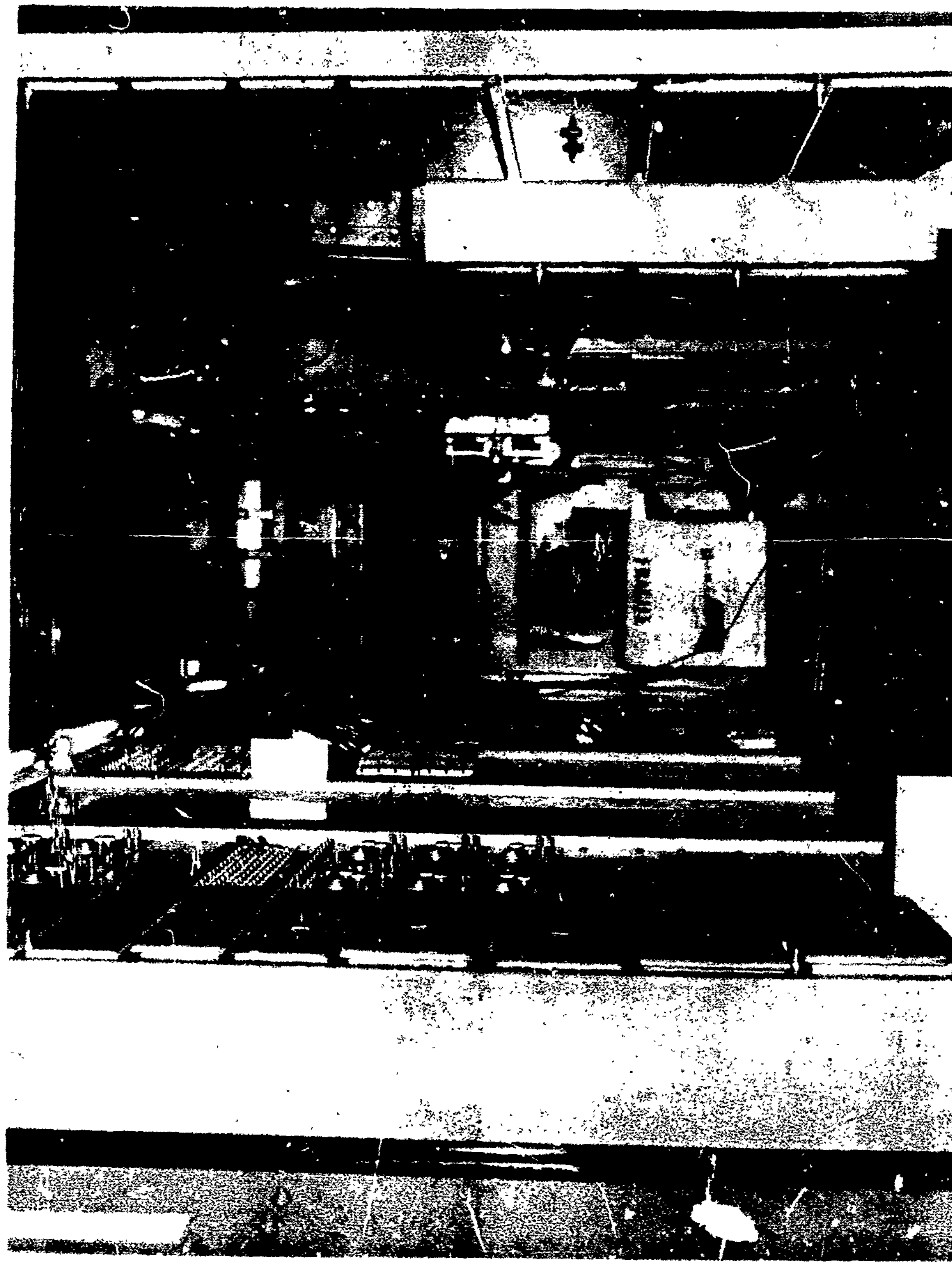


Figure 9. Flight Dynamics Lab Van Interior

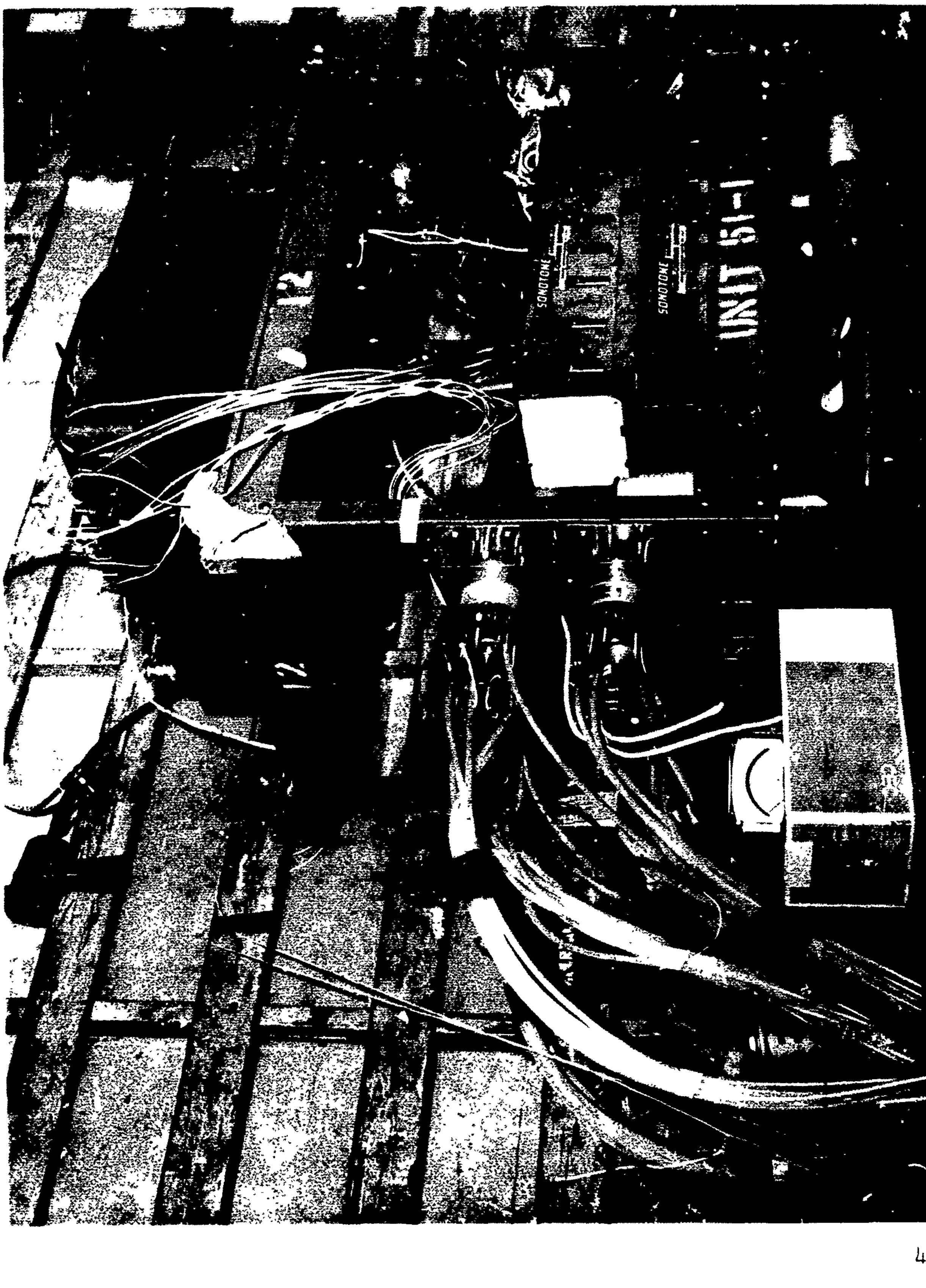


Figure 10. PRESSURE DATA RECORDERS, L. T. V. VAN

Figure 11. ANEMOMETER DATA RECORDER, L. P. V. [illegible]

FIGURE 12 FAILED ANEMOMETER

FIGURE 13 FOREST RESCUE SITE - AERIAL VIEW

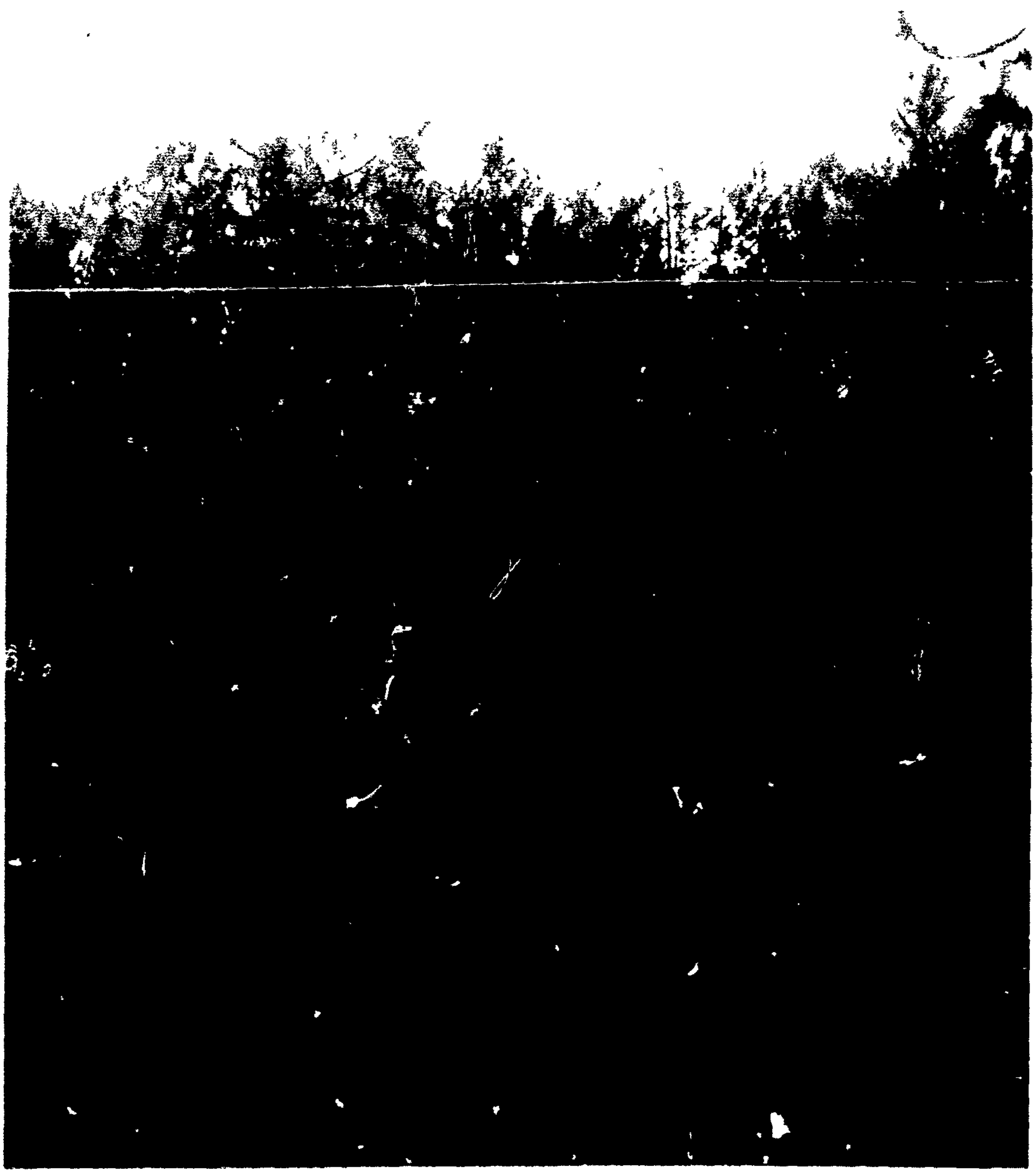
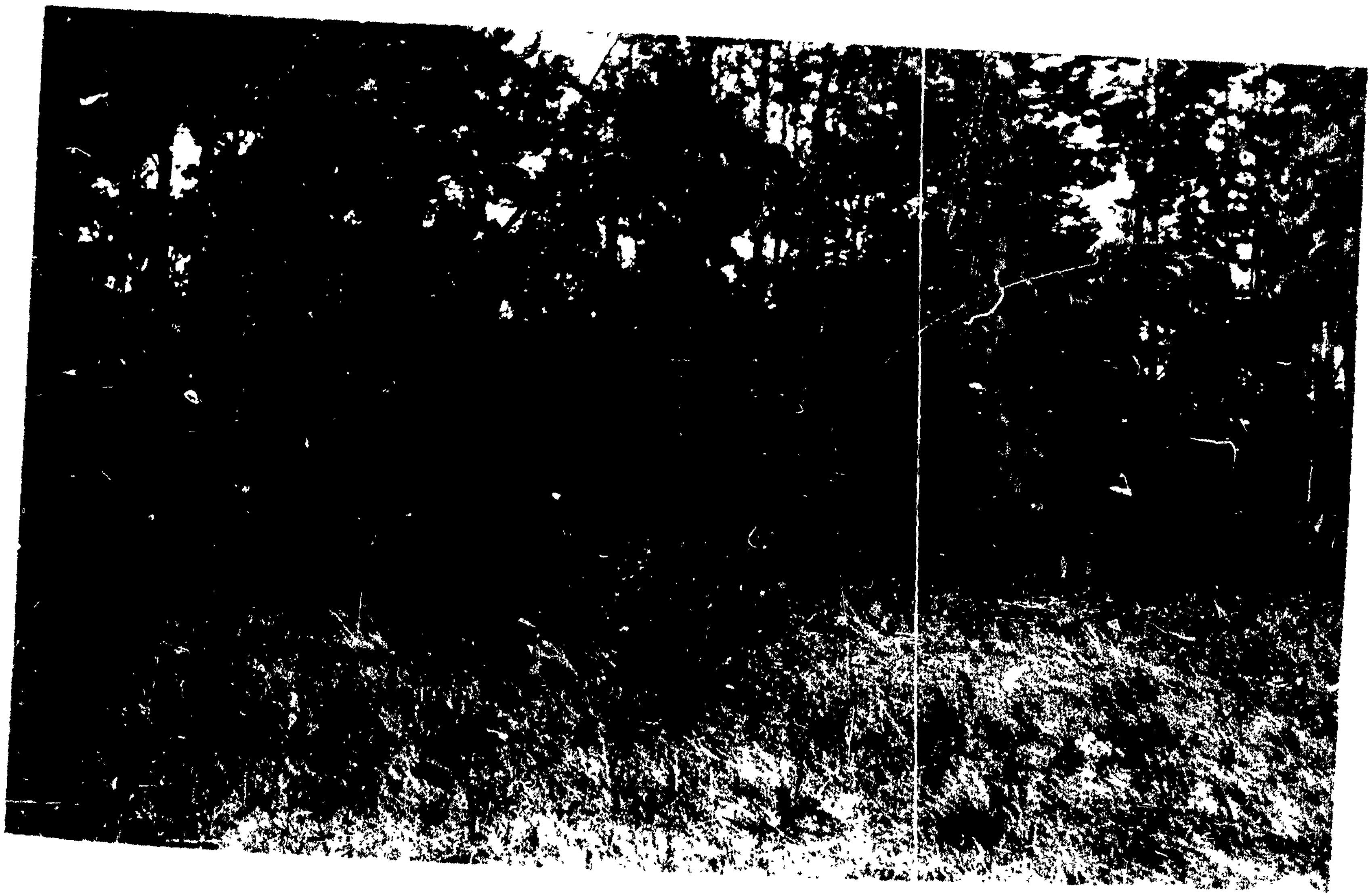


Figure 14.
XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67.
FOREST SITE - BEFORE TEST.

Figure 15
XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67.
FOREST TEST SITE (AFTER H-53 HOVER).

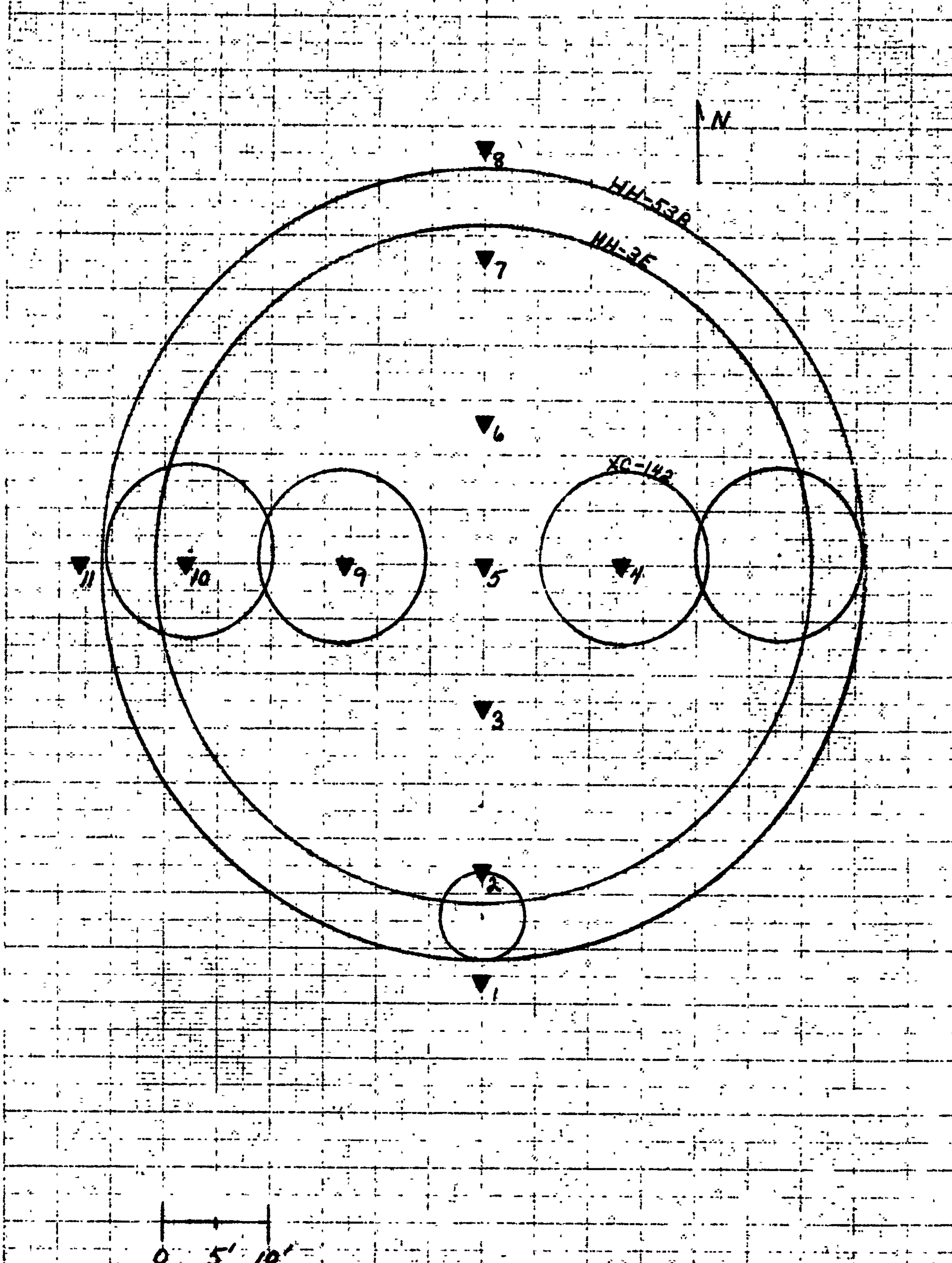


XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67.
FOREST TEST SITE (AFTER H-53 HOVER).

Figure 17
XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67.
FOREST TEST SITE DURING XC-142 HOVER.

Figure 18.
XC-142 DOWNWASH SURVEY TEST, EGLIN AFB, FLORIDA, AUG 21-25-67.
FOREST TEST SITE (AFTER H-53 AND XC-142 HOVER).

FIGURE 18
ANEMOMETER LAYOUT WITH
DISC AREAS SUPERIMPOSED



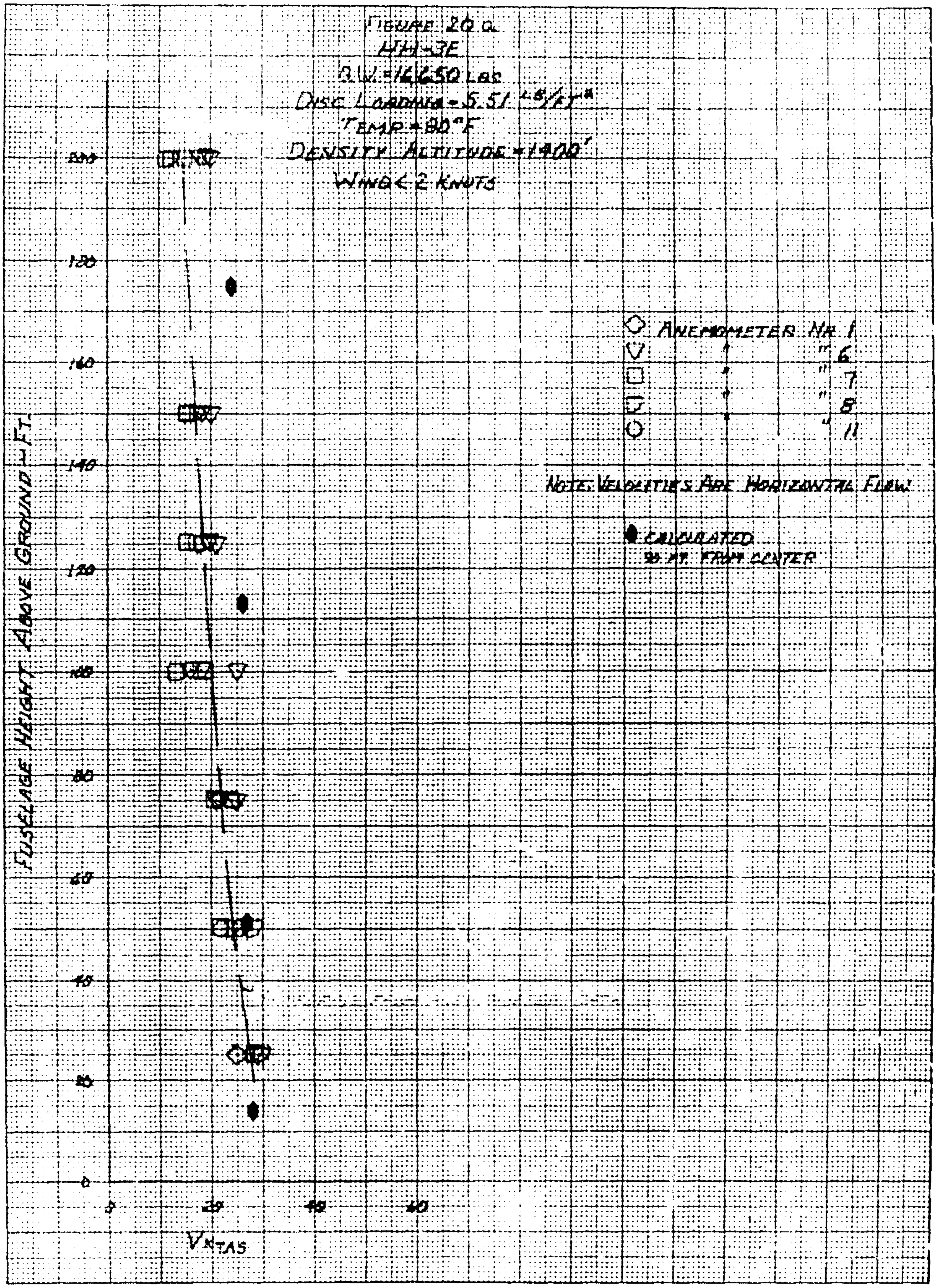
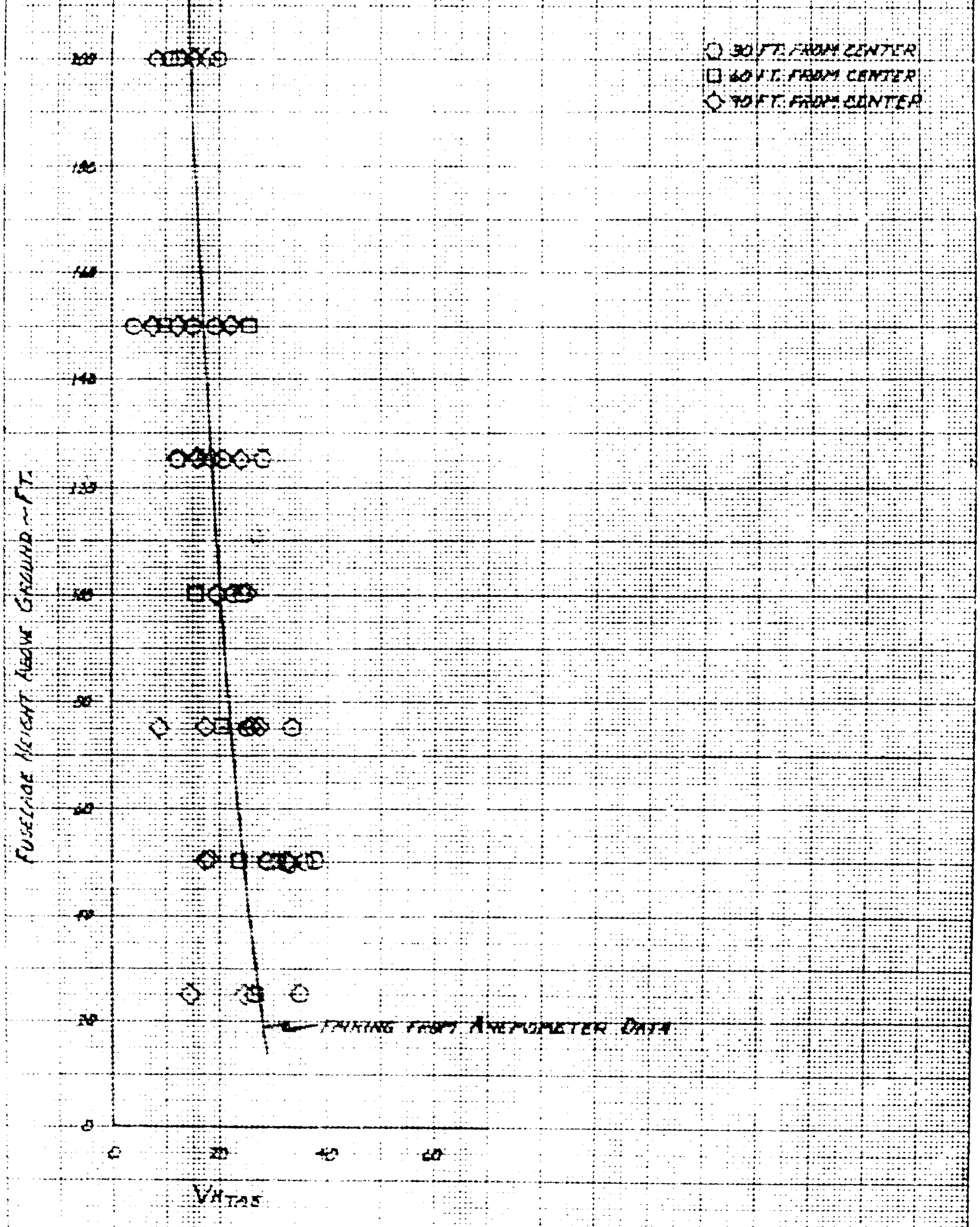


FIGURE 20 a
HH-3E
G.W. = 16250 LBS
DISC LOADING = 5.51 LB/FT²
TEMP = 80°F
DENSITY ALTITUDE = 1400'
WIND < 2 KNOTS
ANEMOMETER NR. 1
" 6
" 7
" 8
" 11
NOTE: VELOCITIES ARE HORIZONTAL FLOW
CALCULATED
FT. FROM CENTER
FUSELAGE HEIGHT ABOVE GROUND ~ FT.
180
160
140
120
100
80
60
40
20
0
20
40
60
VK TAS

FIGURE 20b.

HH-3E

PRESSURE PROBES 4 FT. ABOVE GROUND



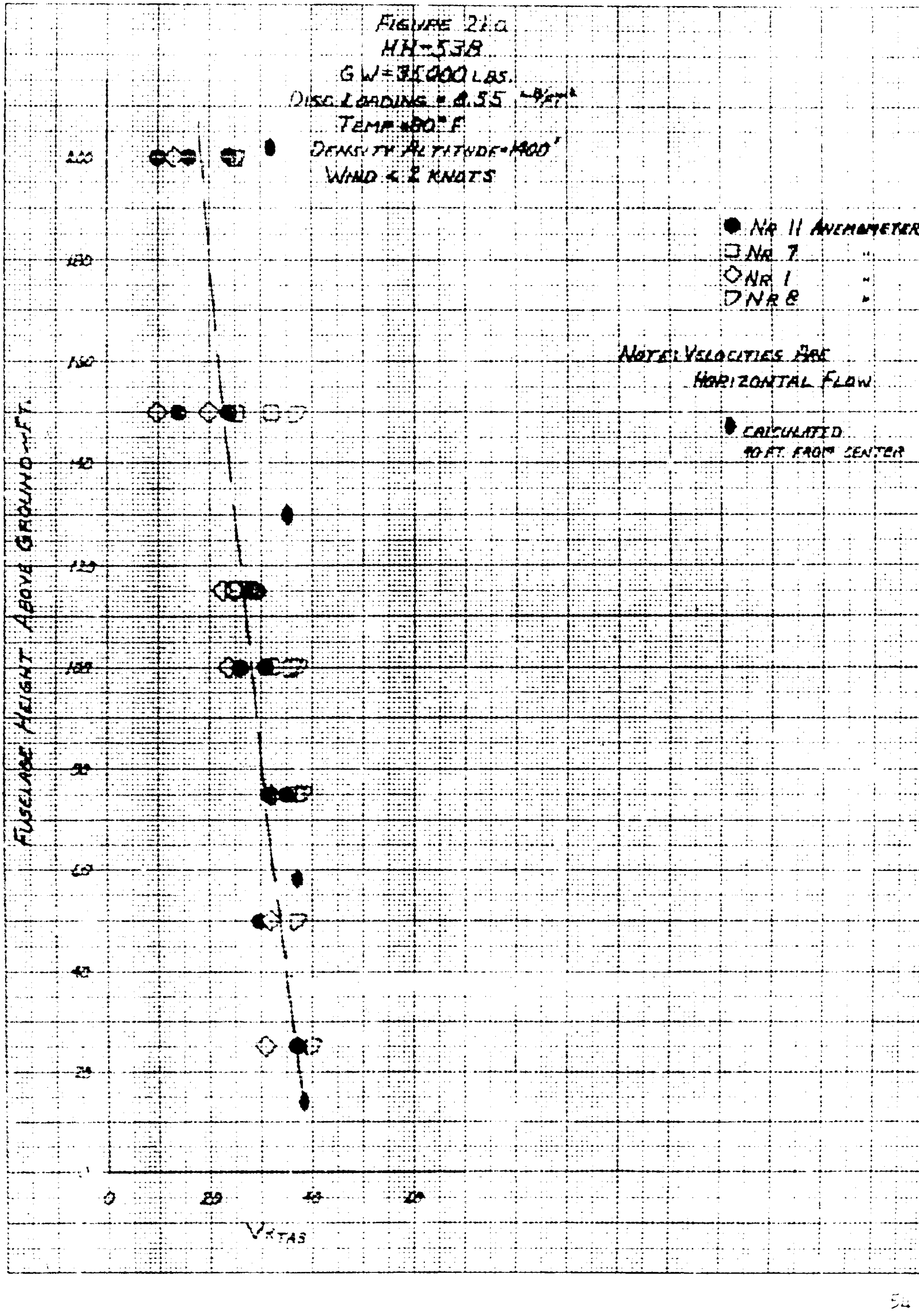


FIGURE 21.a
HH-53B
WIND < 2 KNOTS
Nr 11 ANEMOMETER
Nr 7
Nr 1
Nr 8
NOTE: VELOCITIES ARE HORIZONTAL FLOW
CALCULATED
FUSELAGE HEIGHT ABOVE GROUND — FT.
0
20
40
60
V KTAS

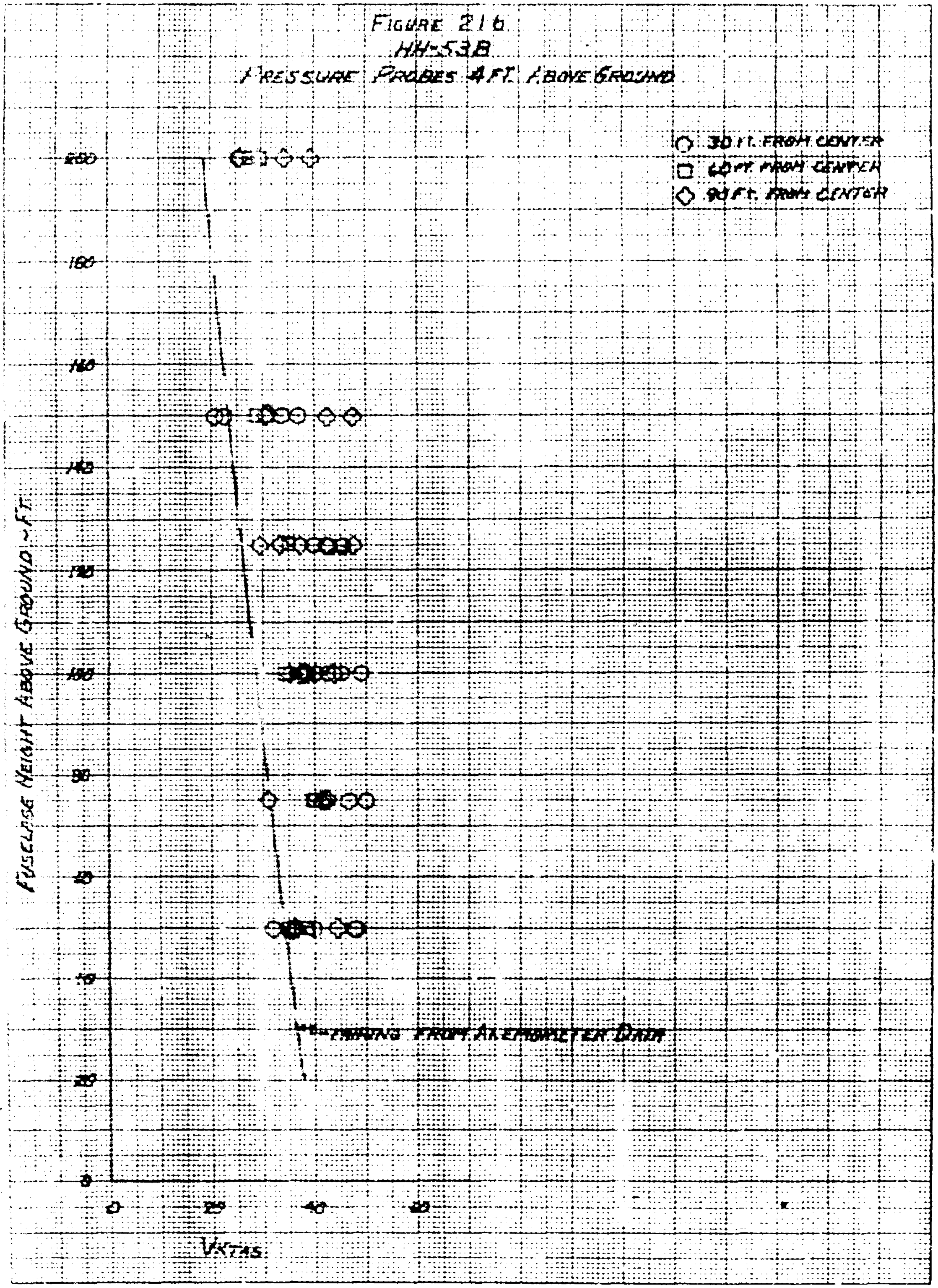


FIGURE 21b
HH-53B
PRESSURE PROBES 4 FT. ABOVE GROUND
30 FT. FROM CENTER
60 FT. FROM CENTER
90 FT. FROM CENTER
FUSELAGE HEIGHT ABOVE GROUND ~ FT.
200
180
160
140
120
100
80
60
40
20
0
FAIRING FROM ANEMOMETER DATA
0
20
40
60
V_{KTAS}

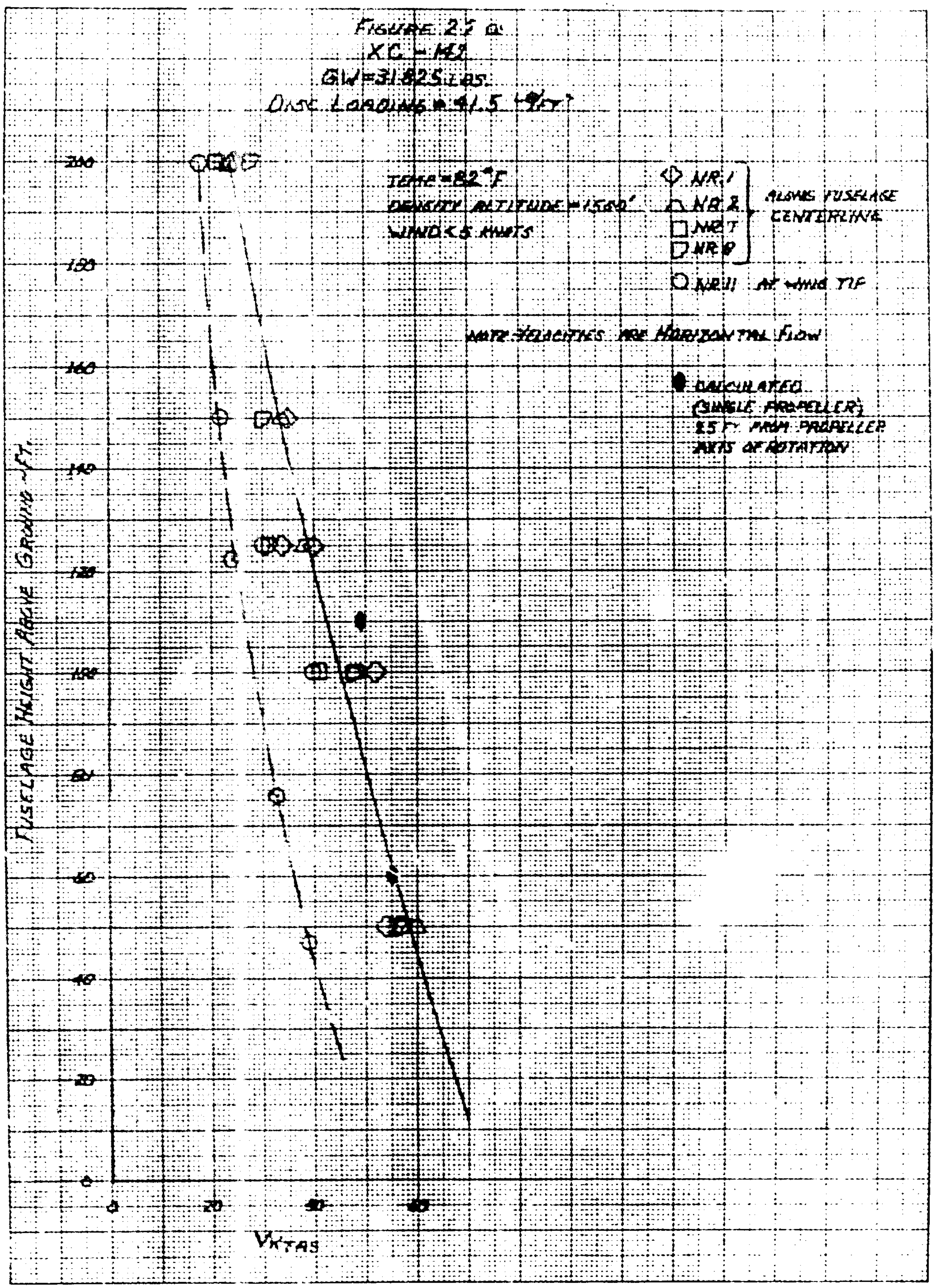


FIGURE 27 a
XC - 142
GW = 31825 LBS.
DISC LOADING = 41.5 #/FT²
TEMP = 82 °F
DENSITY ALTITUDE = 1500'
WIND < 5 KNOTS
NR 1
NR 2
NR 7
NR 8
ALONG FUSELAGE CENTERLINE
NR 11 AT WING TIP
NOTE: VELOCITIES ARE HORIZONTAL FLOW
CALCULATED (SINGLE PROPELLER) 25 FT FROM PROPELLER AXIS OF ROTATION
FUSELAGE HEIGHT ABOVE GROUND ~FT.
200
180
160
140
120
100
80
60
40
20
0
0
20
30
40
VKTAS

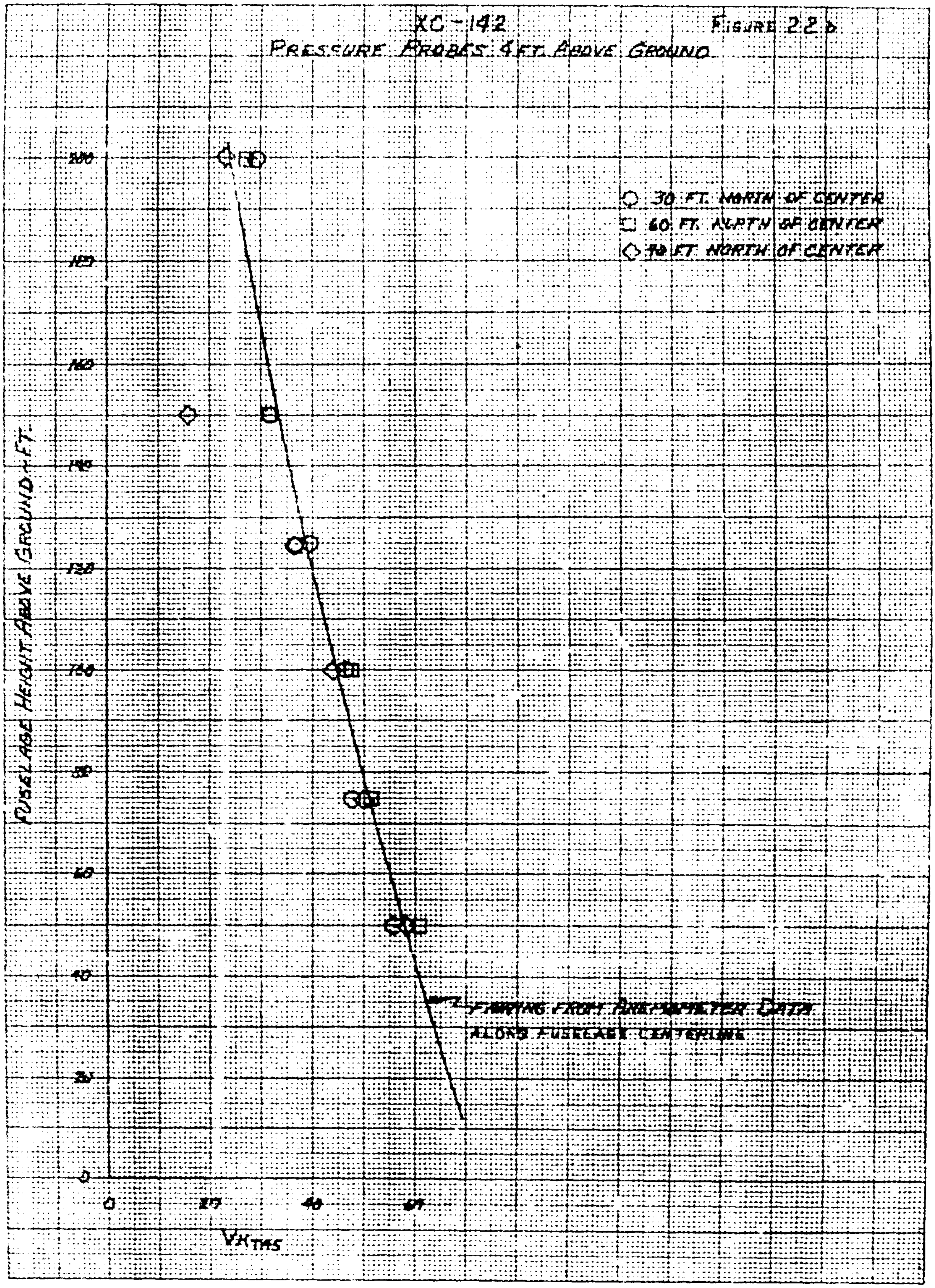

XC-142
FIGURE 22 b
PRESSURE PROBES 4 FT. ABOVE GROUND
30 FT. NORTH OF CENTER
60 FT. NORTH OF CENTER
90 FT. NORTH OF CENTER
FAIRING FROM ANEMOMETER DATA
ALONG FUSELAGE CENTERLINE
FUSELAGE HEIGHT ABOVE GROUND ~ FT.
$V_{X_{TAS}}$
0
20
40
60
80
100
120
140
160
180
200

FIGURE 23
COMPARISON OF
DOWNWASH VELOCITIES

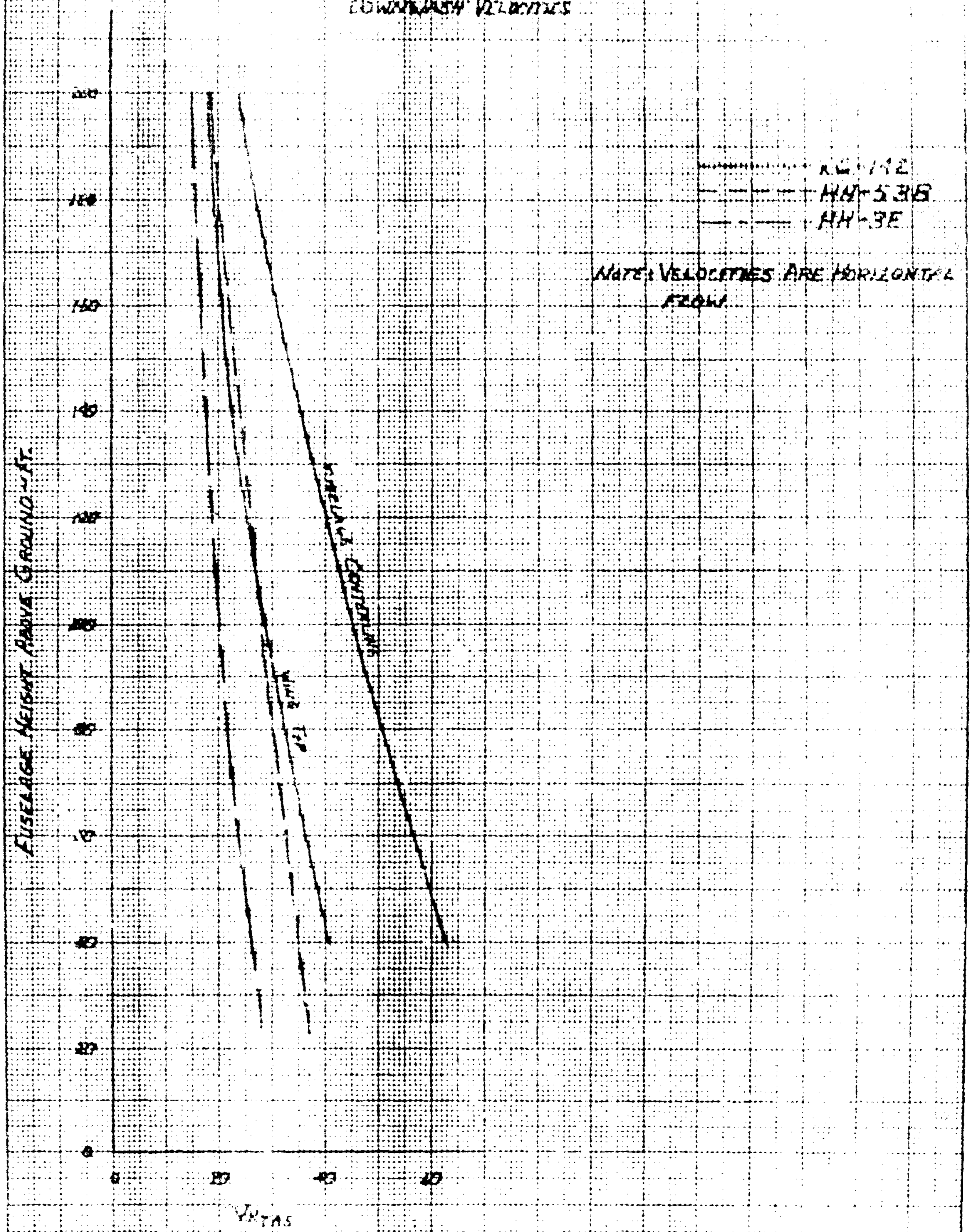


FIGURE 24
REFERRED PROP/ROTOR HEIGHT
VS DYNAMIC PRESSURE RATIO

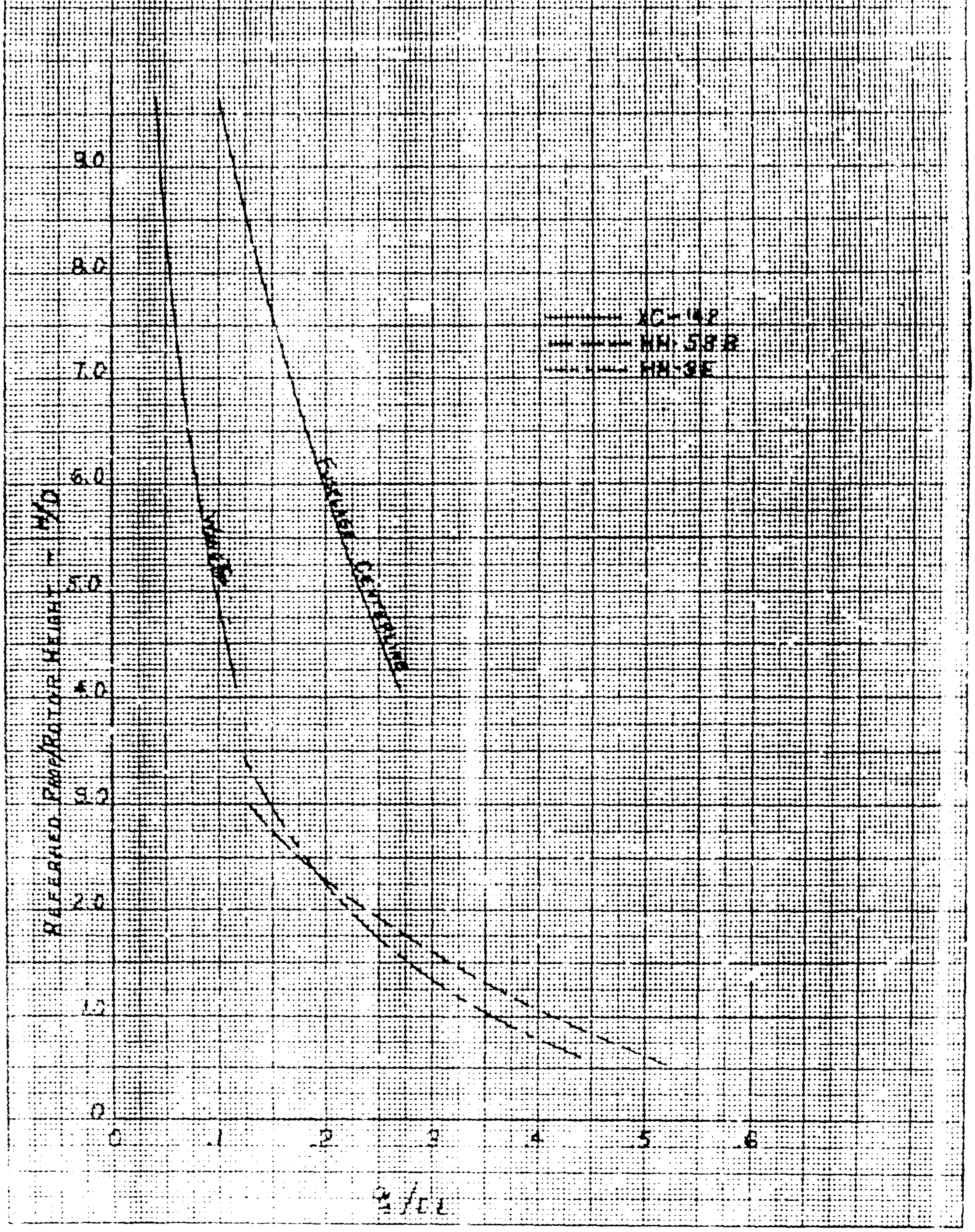


Figure 25 - Average Sound Pressure Level in 1/3 Octave Bands Below HH-53B and HH-3E Aircraft

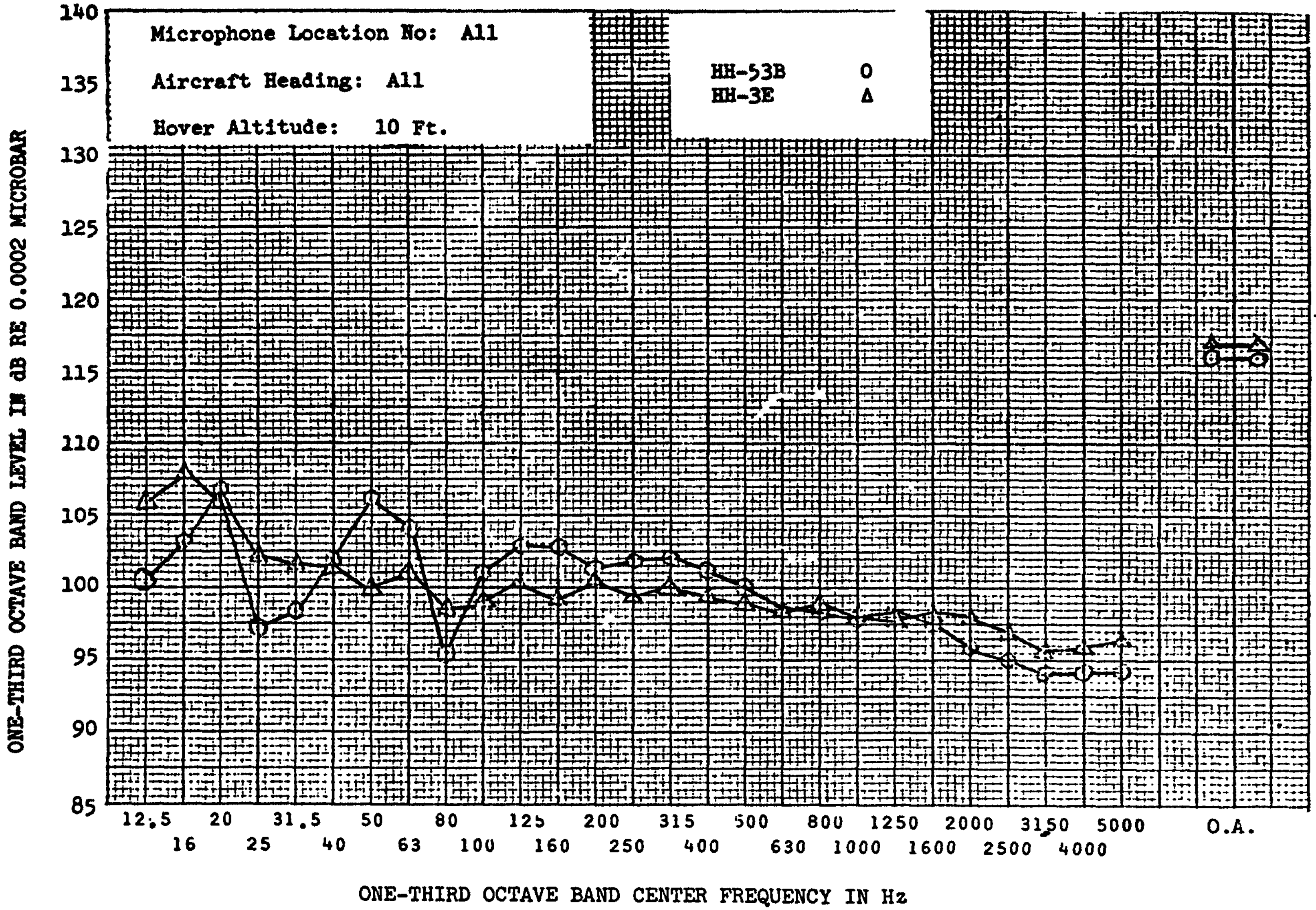


Figure 26 - Average Sound Pressure Level in 1/3 Octave Bands Below HH-53B and HH-3E Aircraft

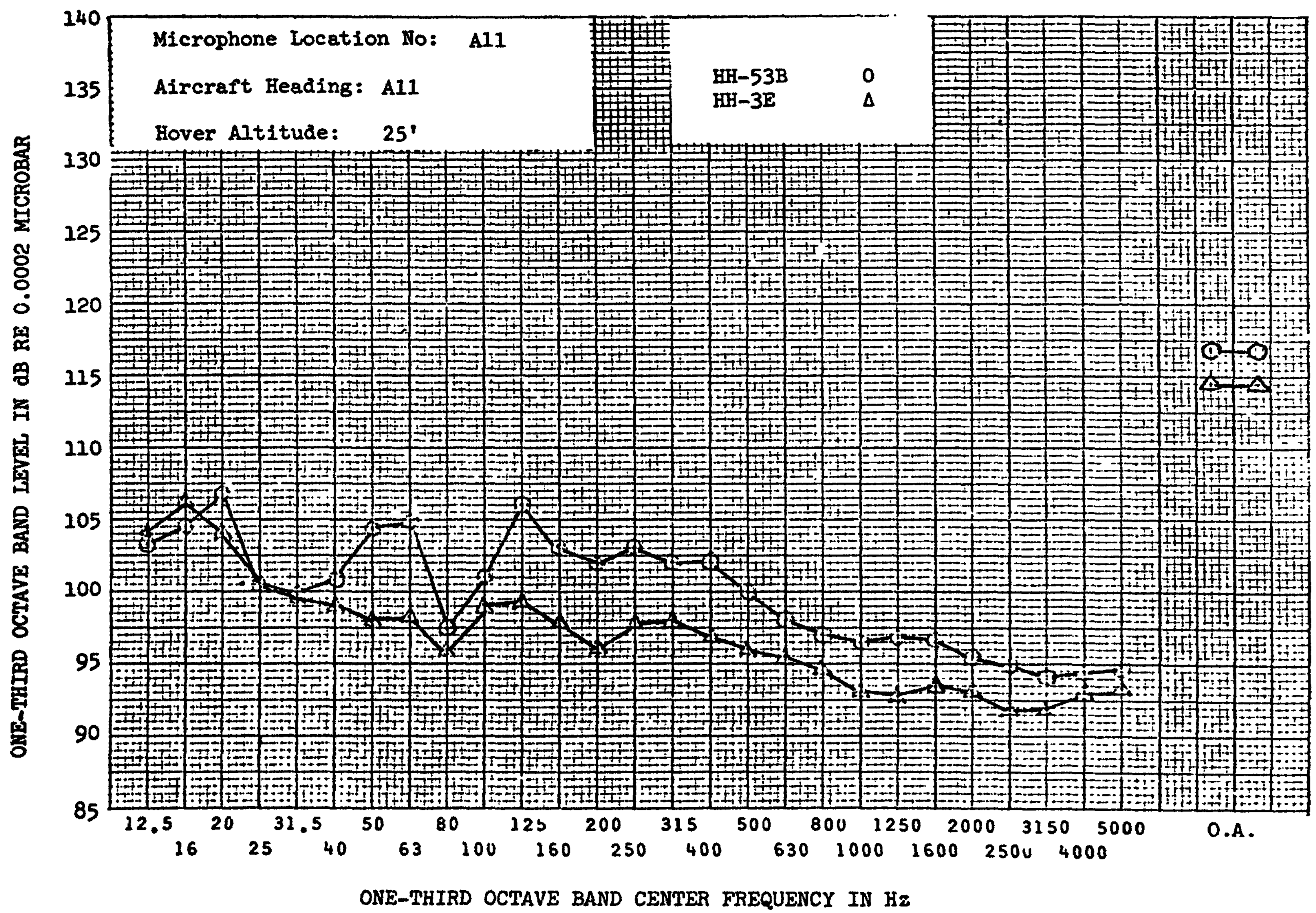


Figure 27 - Average Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

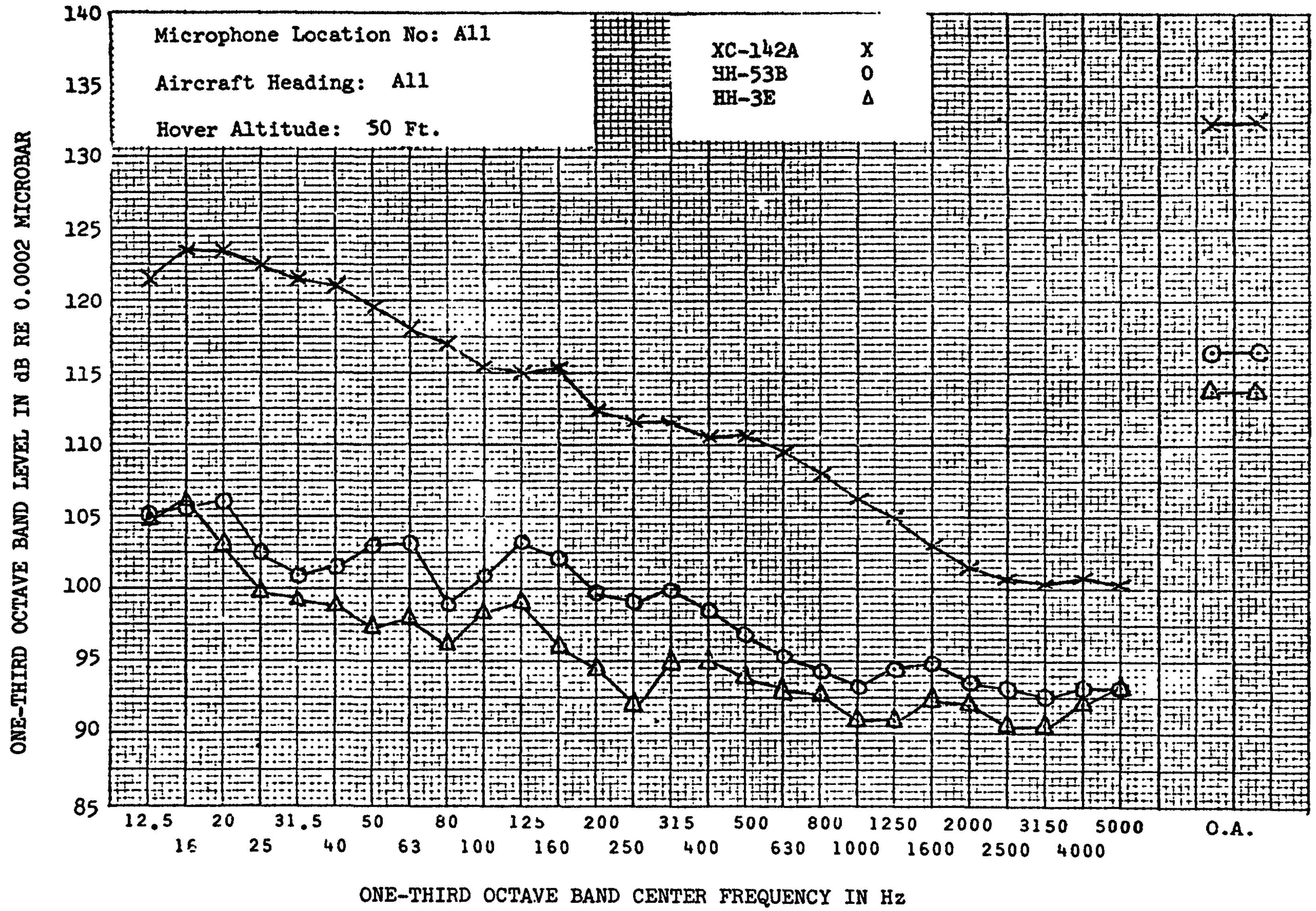


Figure 28 - Average Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

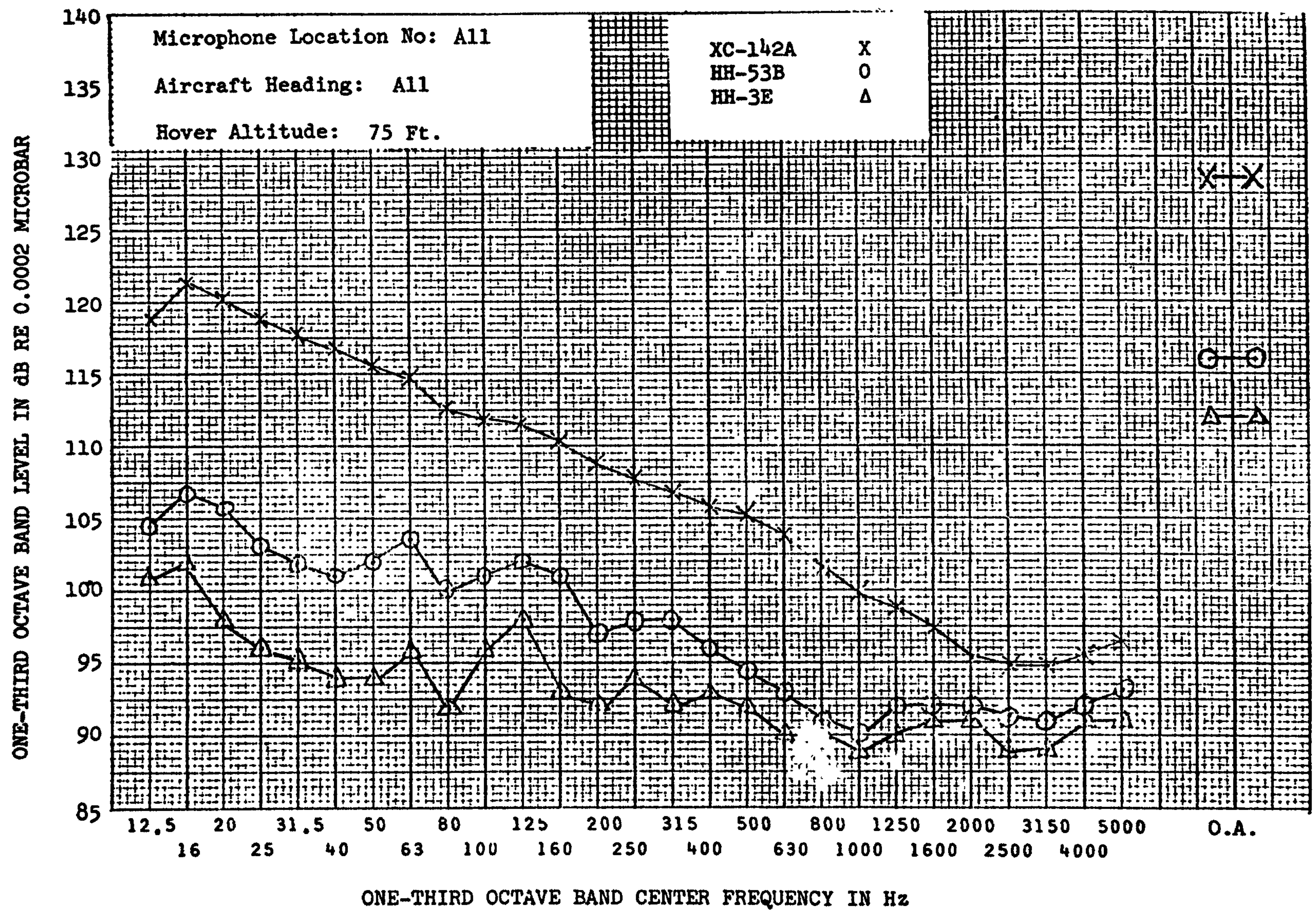


Figure 29 - Average Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

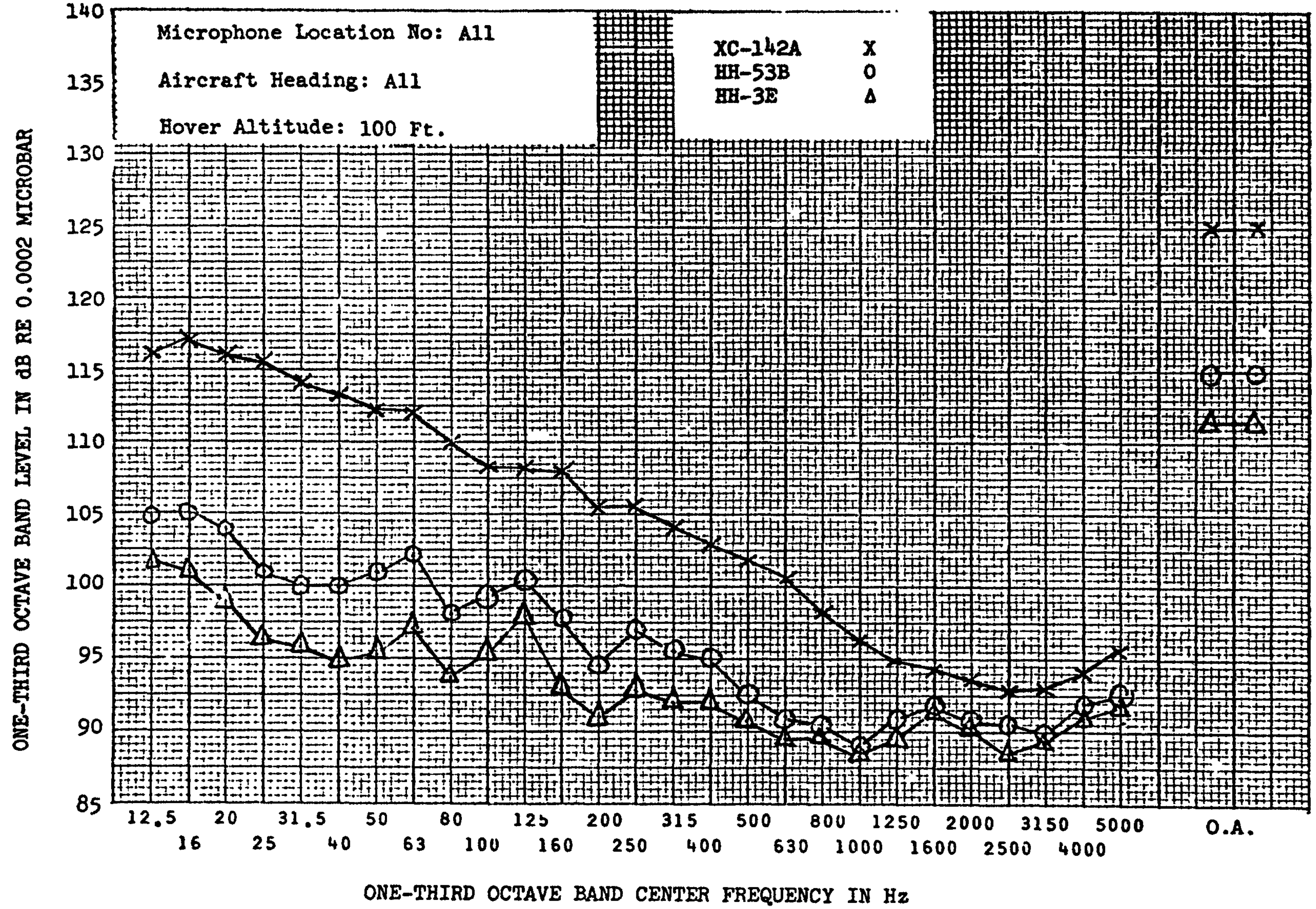


Figure 30 - Average Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

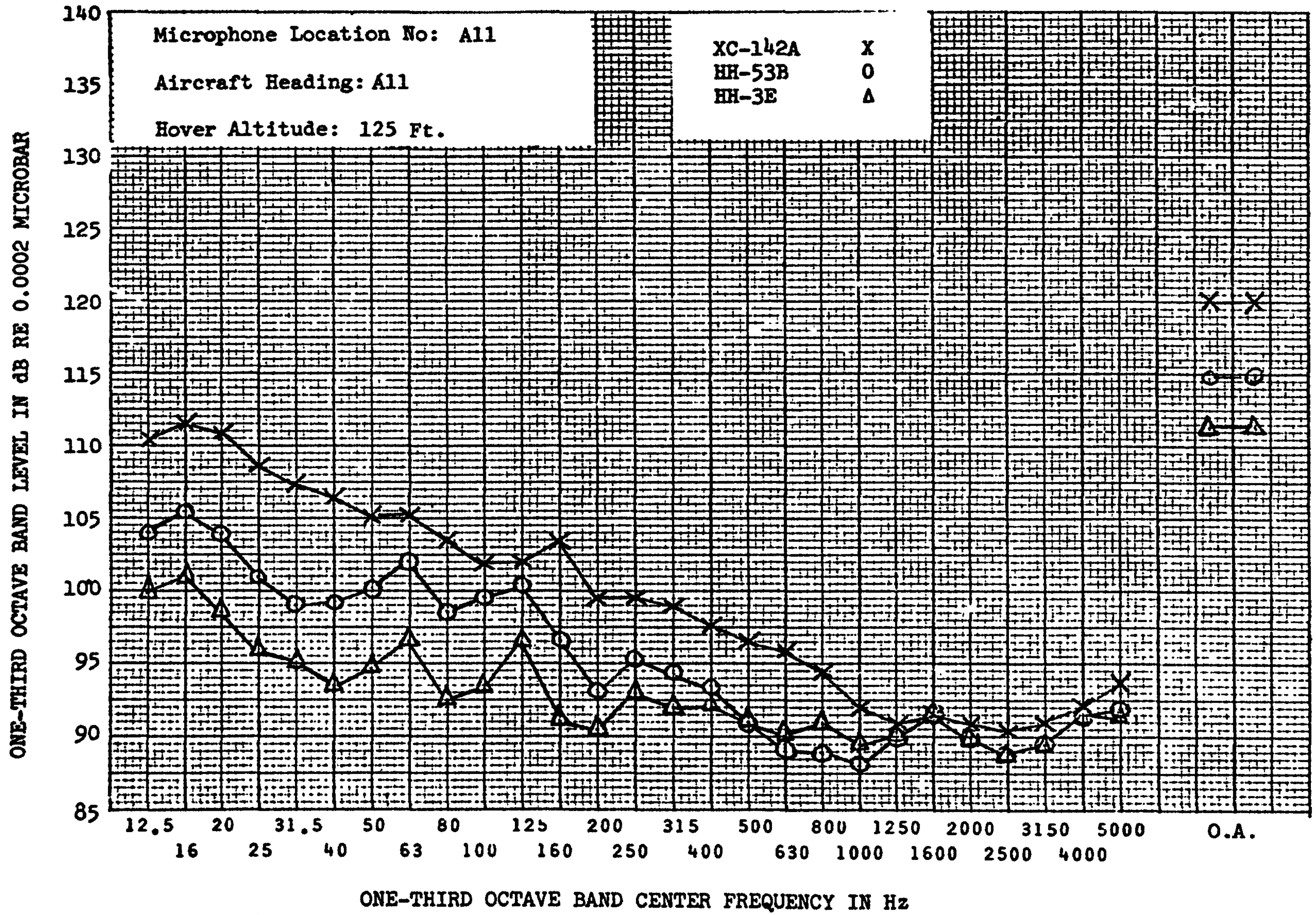


Figure 31 - Average Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

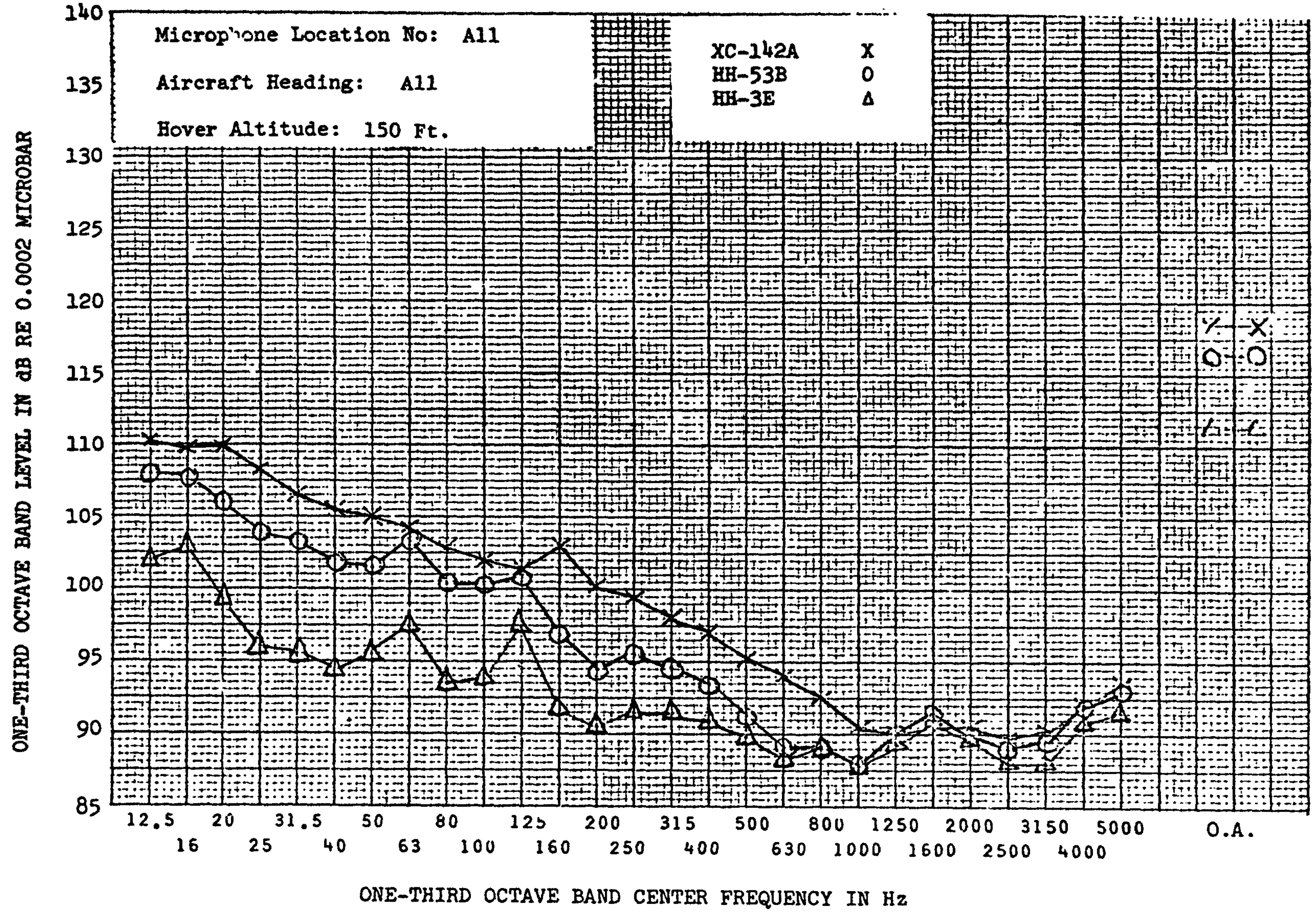


Figure 32 - Average Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

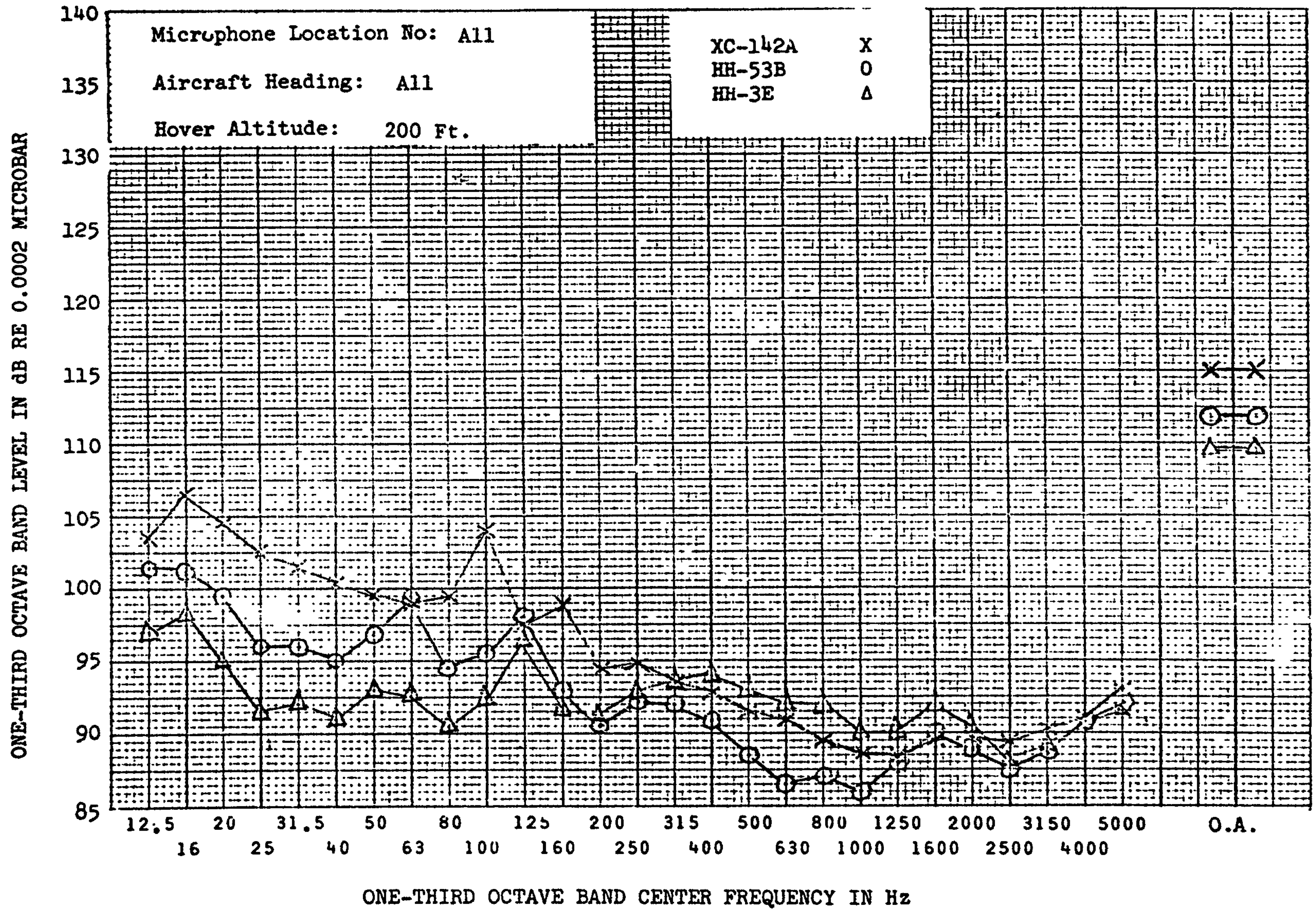


Figure 33 - Average Overall Sound Pressure Level Below XC-142A, HH-53B and HH-3E vs Hover Altitude

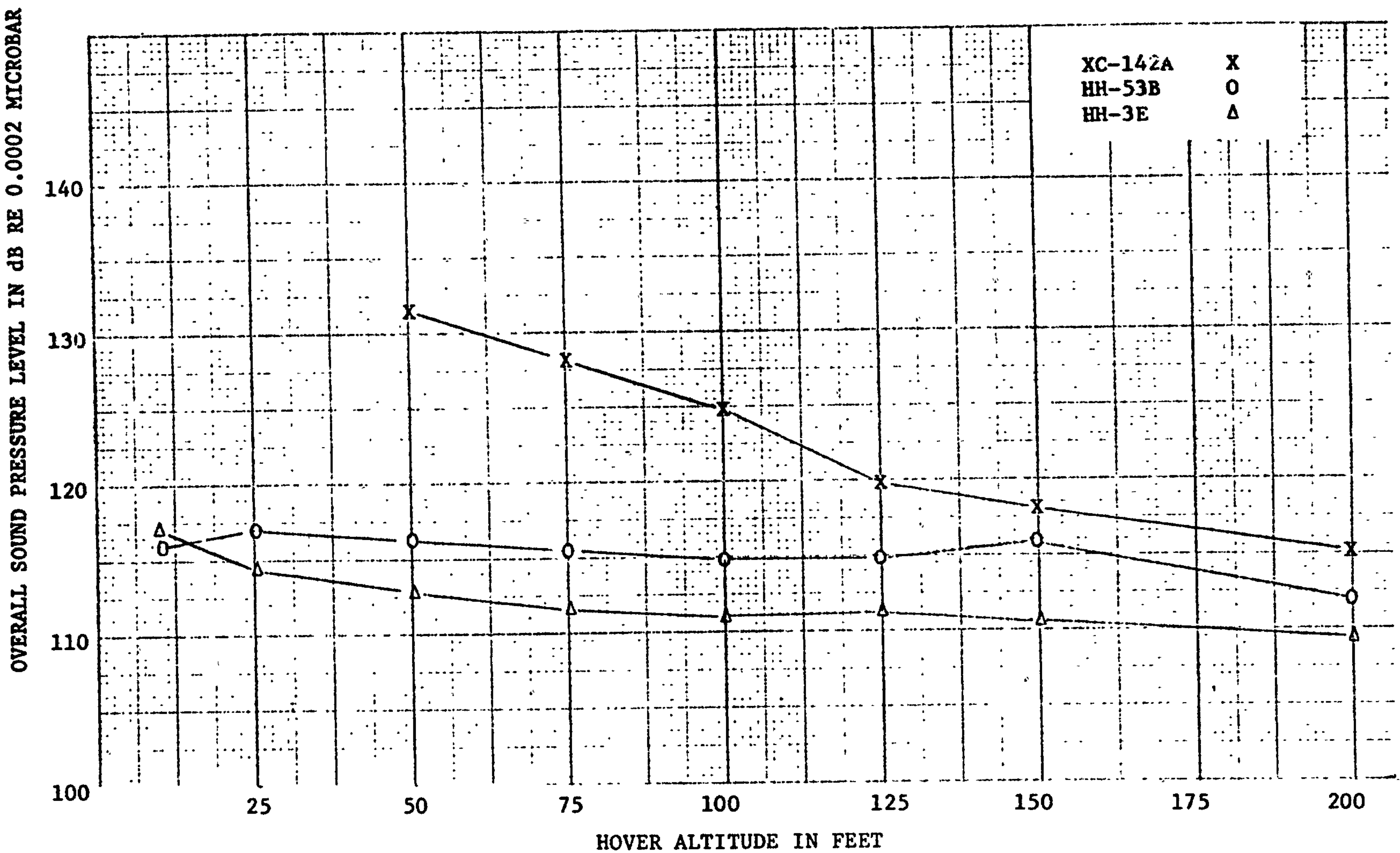


Figure 34 - Maximum Sound Pressure Level in 1/3 Octave Bands Below HH-53B and HH-3E Aircraft

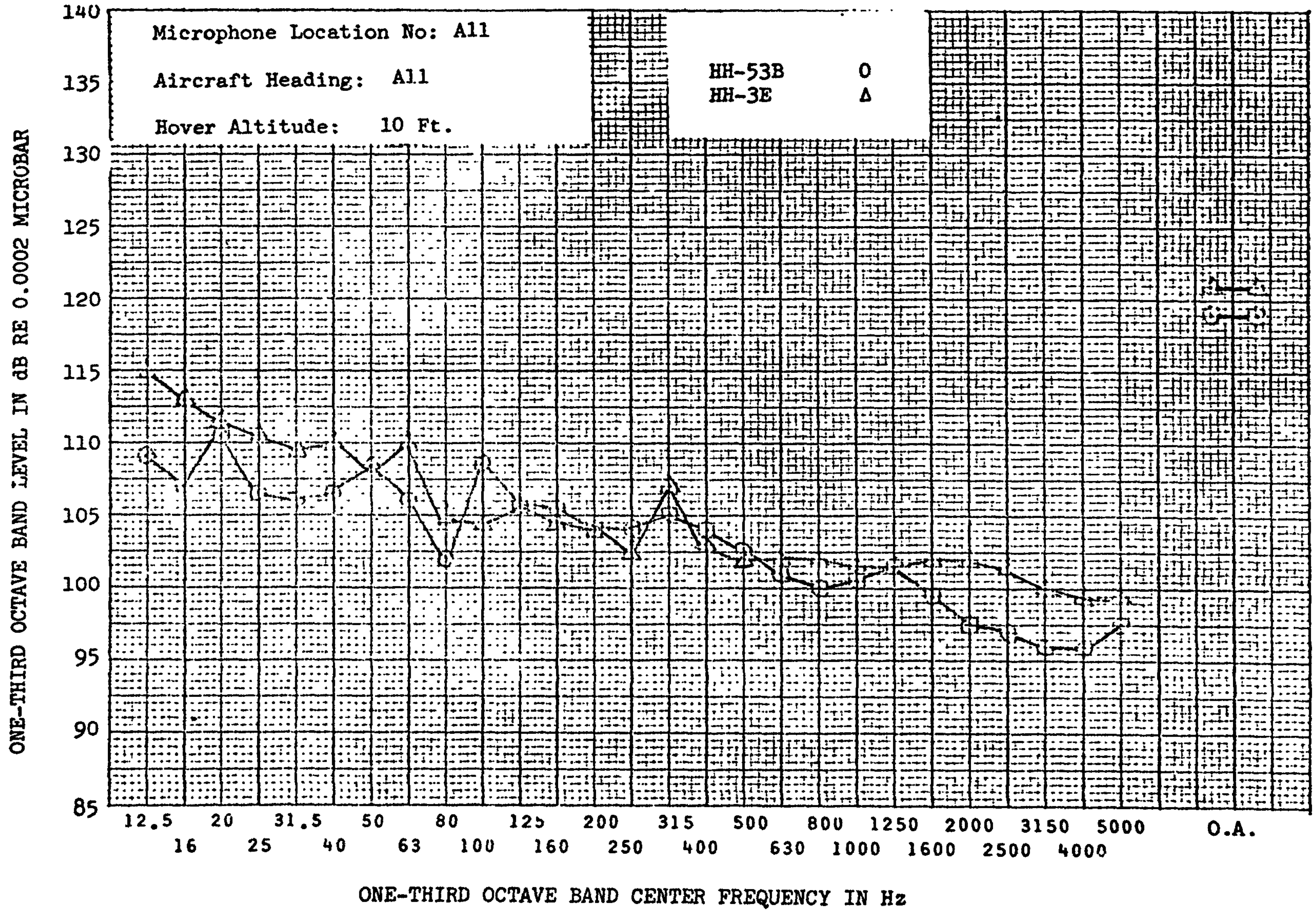


Figure 35 - Maximum Sound Pressure Level in 1/3 Octave Bands Below HH-53B and HH-3E Aircraft

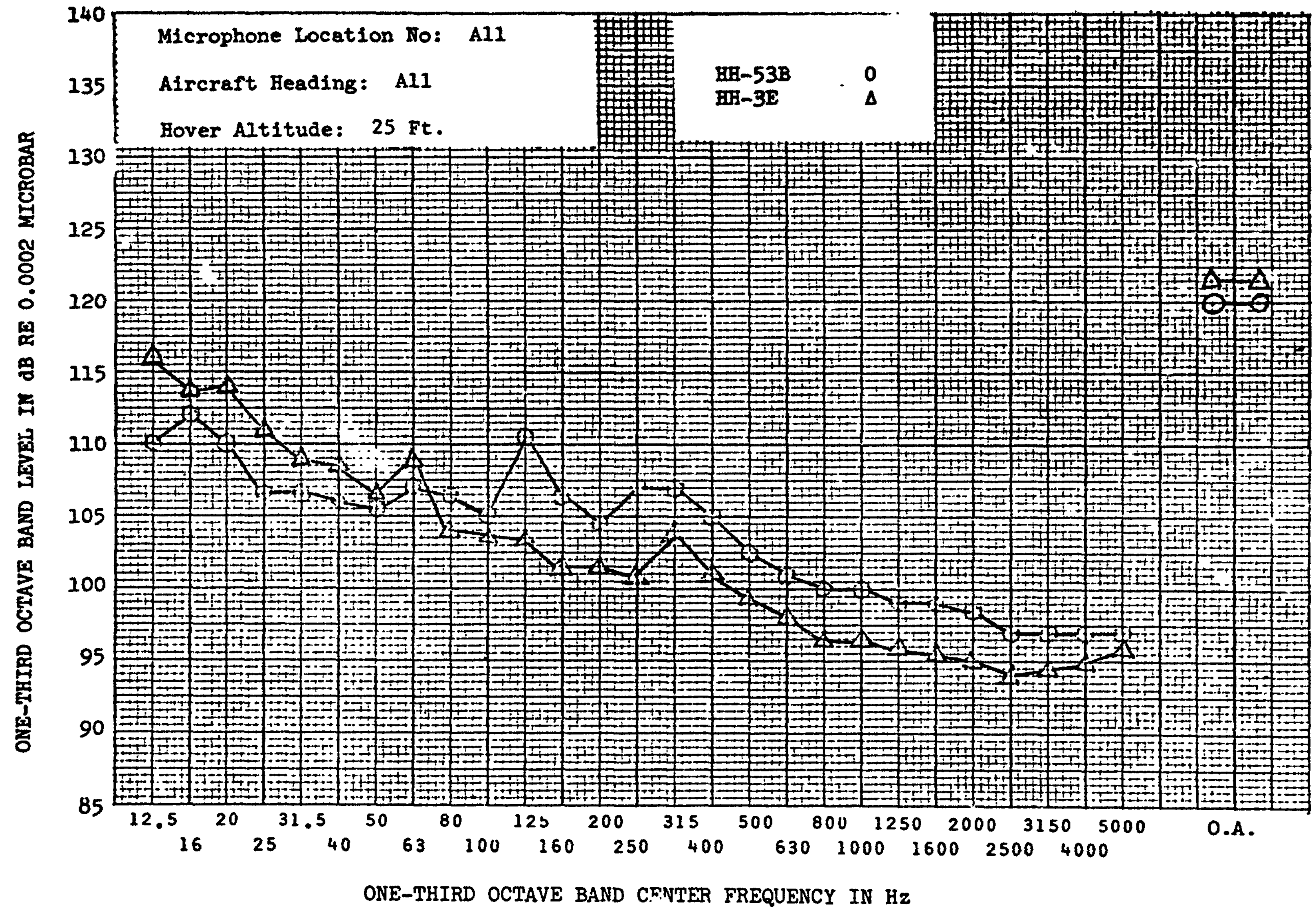


Figure 36 - Maximum Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

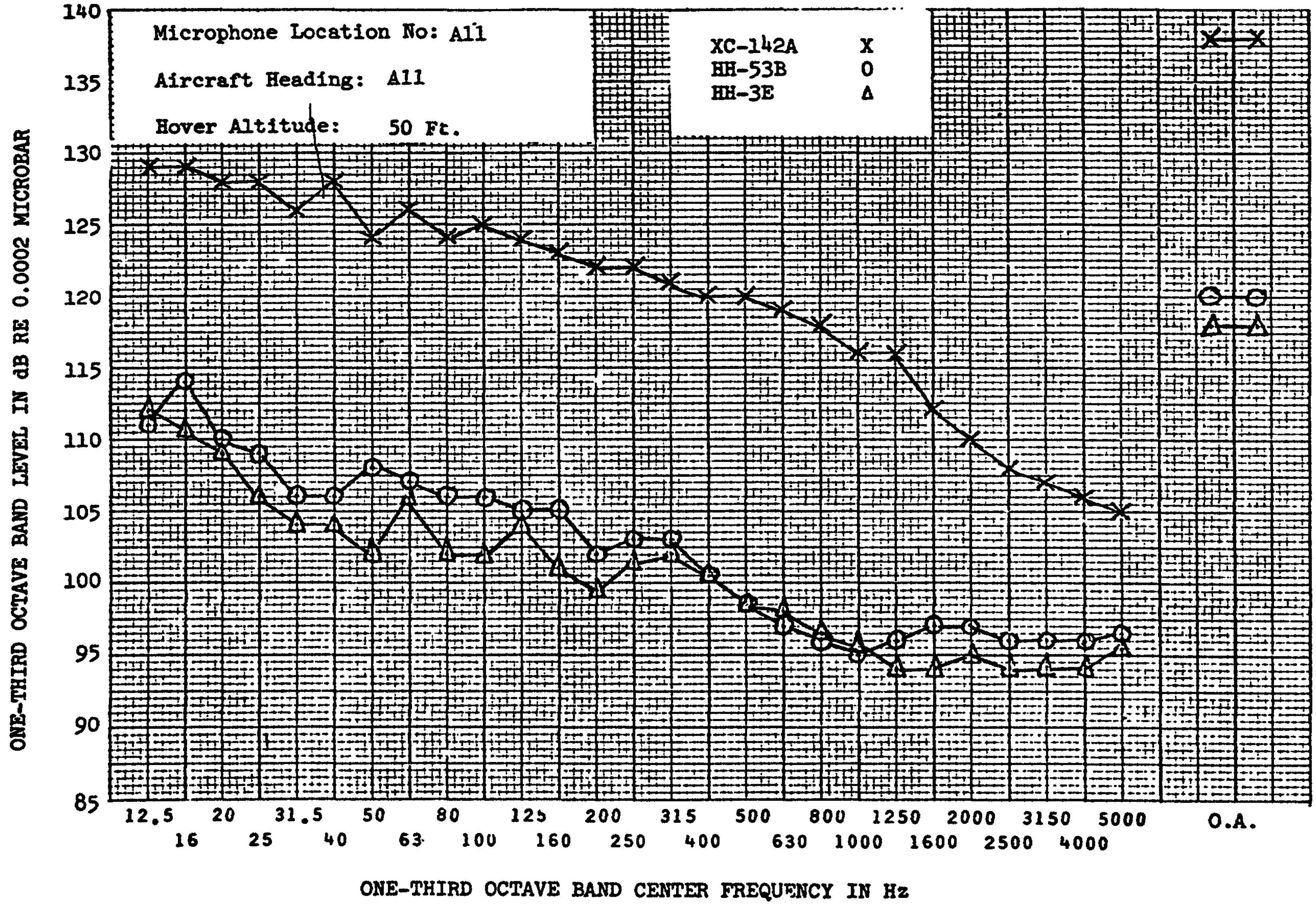


Figure 37 - Maximum Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

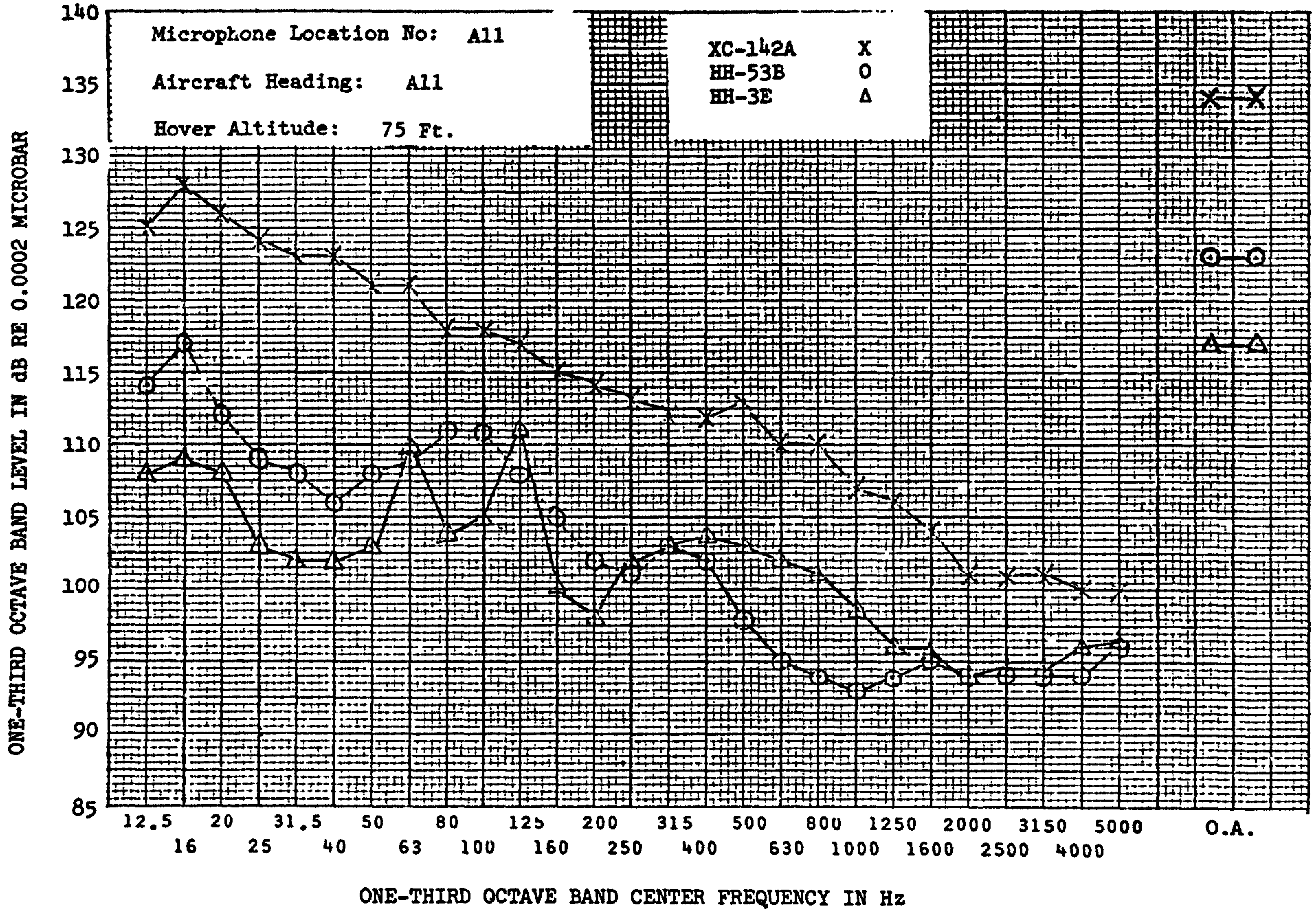


Figure 38- Maximum Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

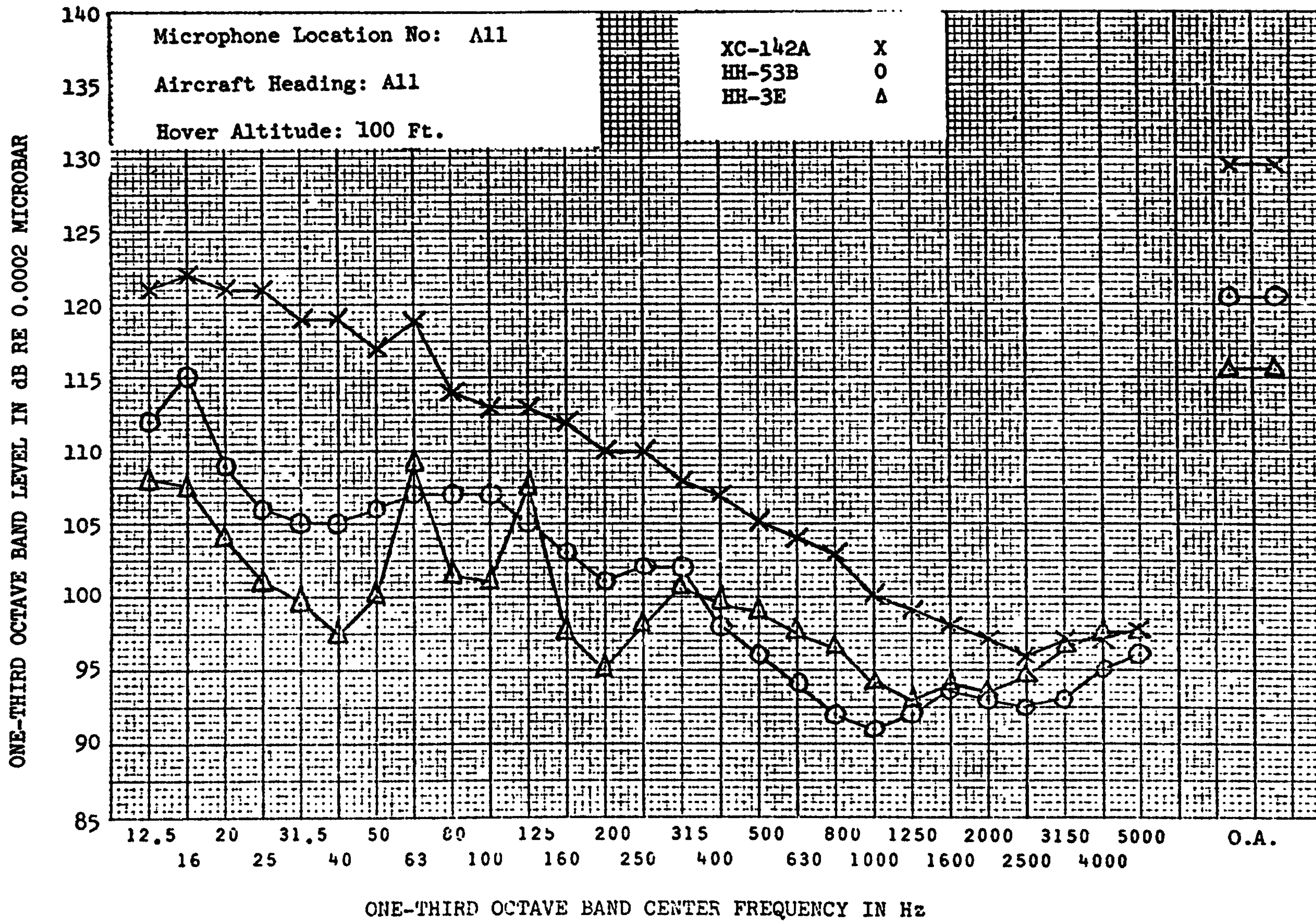


Figure 39 - Maximum Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

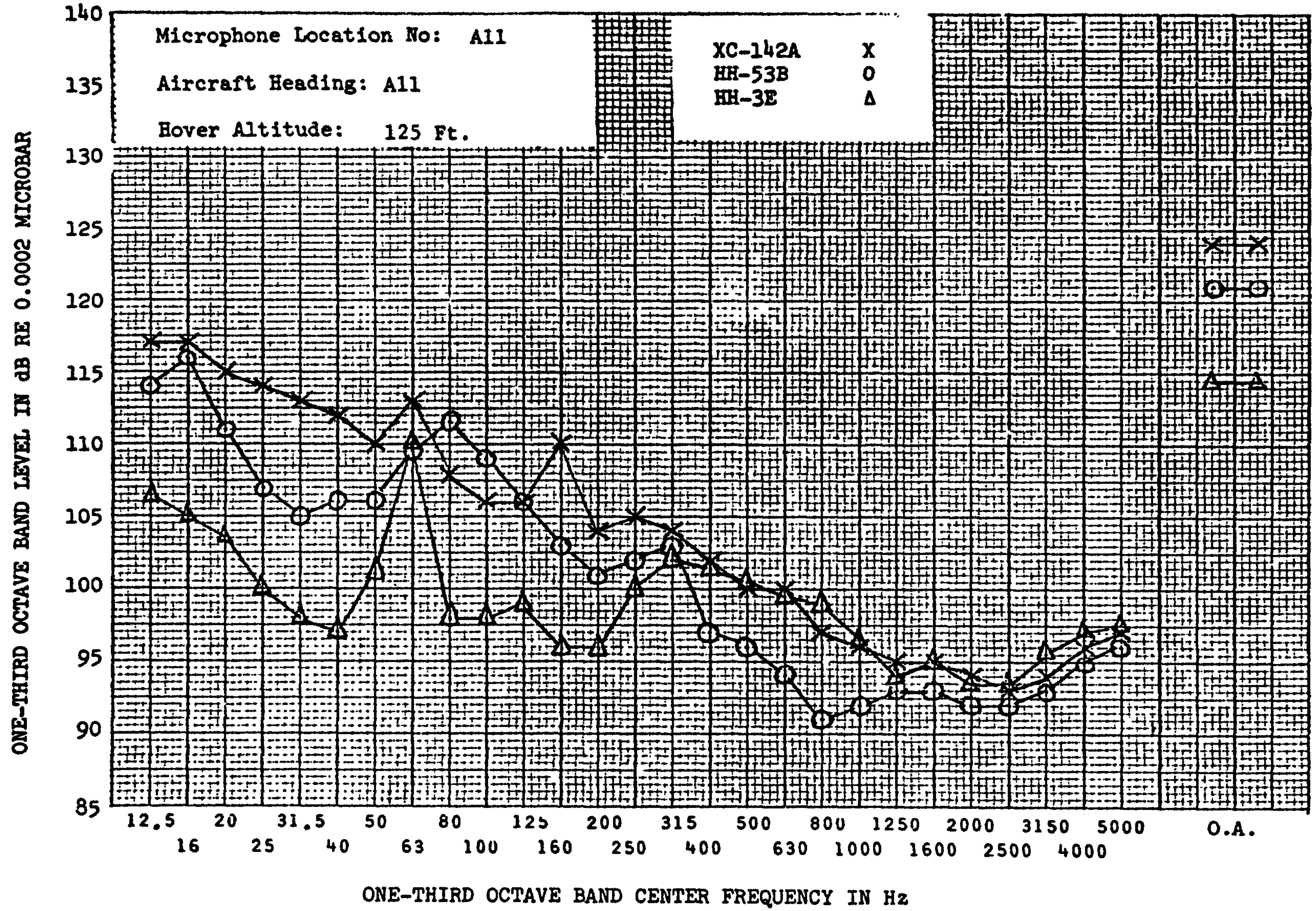


Figure 40 - Maximum Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

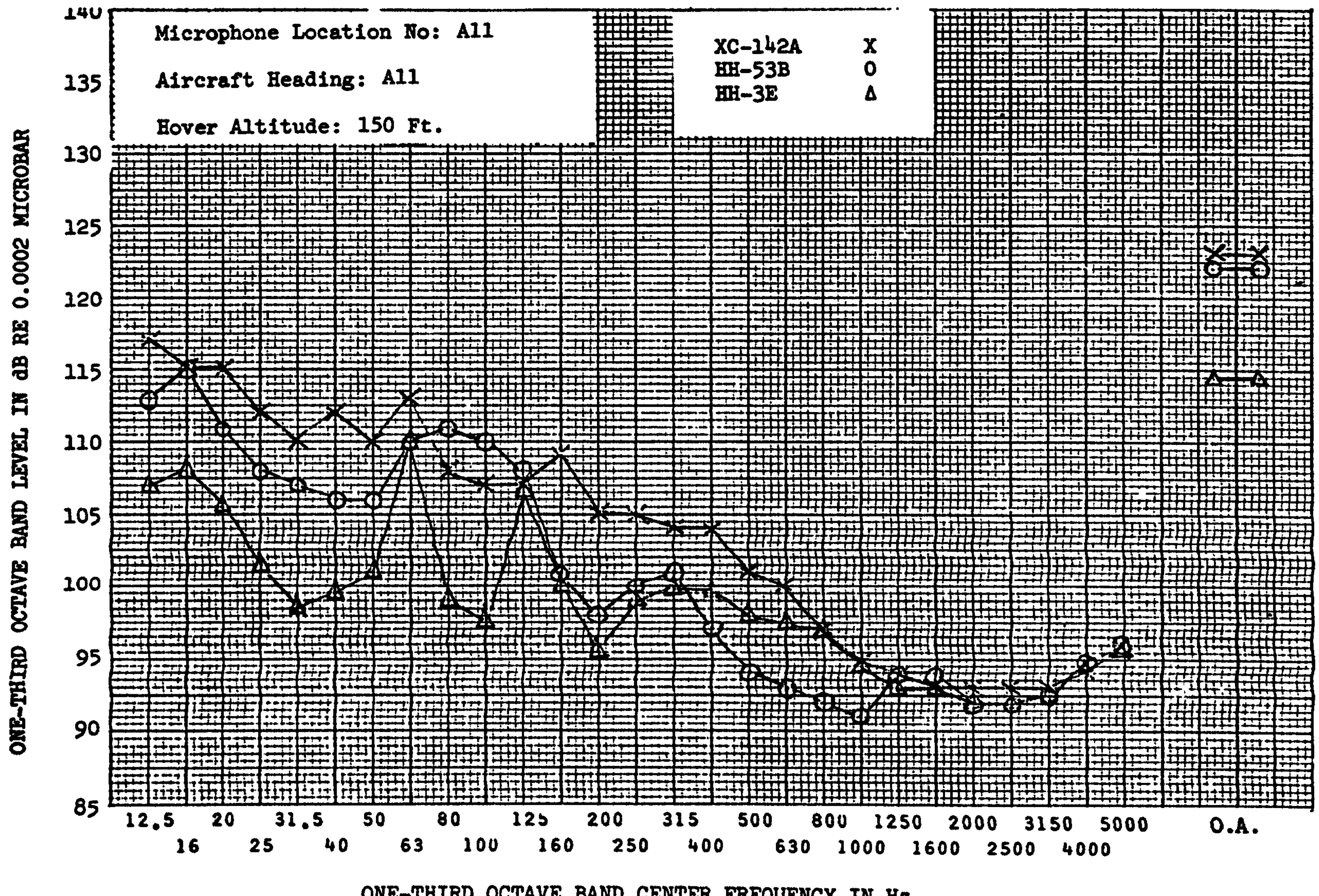


Figure 41 - Maximum Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

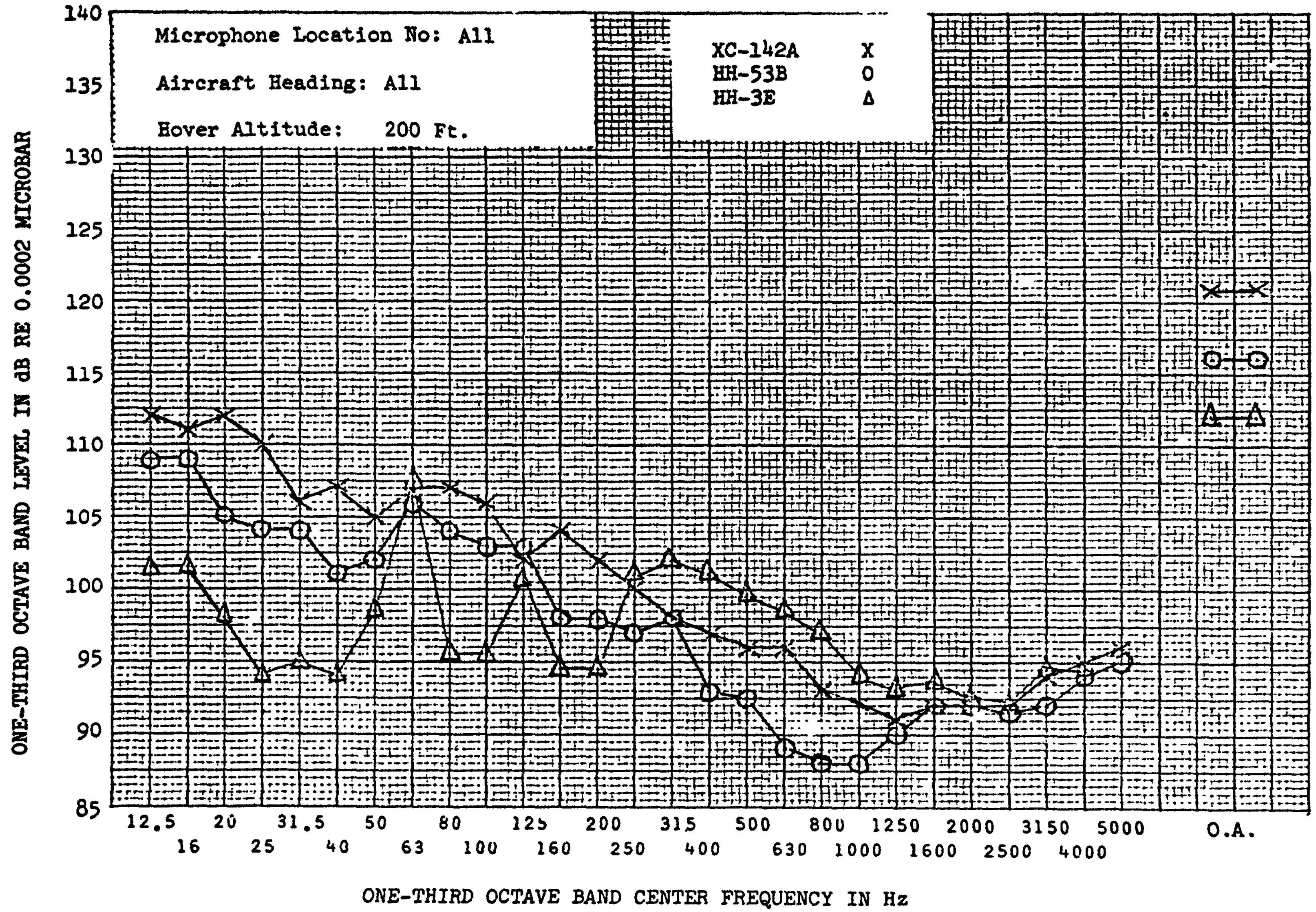


Figure 42 - Maximum Overall Sound Pressure Level Below XC-142A, HH-53B, and HH-3E vs Hover Altitude

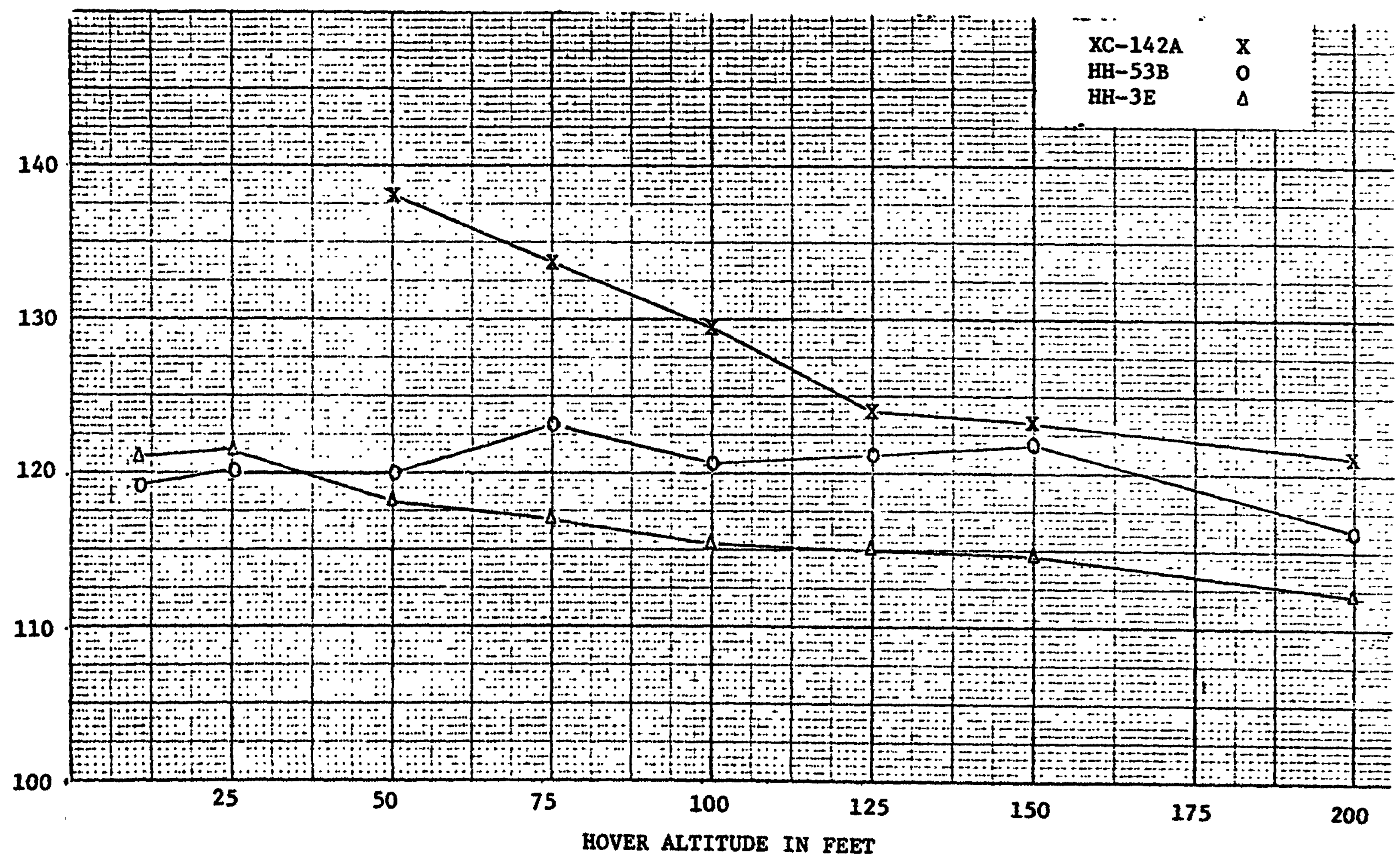


Figure 43 - Sound Pressure Level in 1/3 Octave Bands Below HH-53B and HH-3E Aircraft

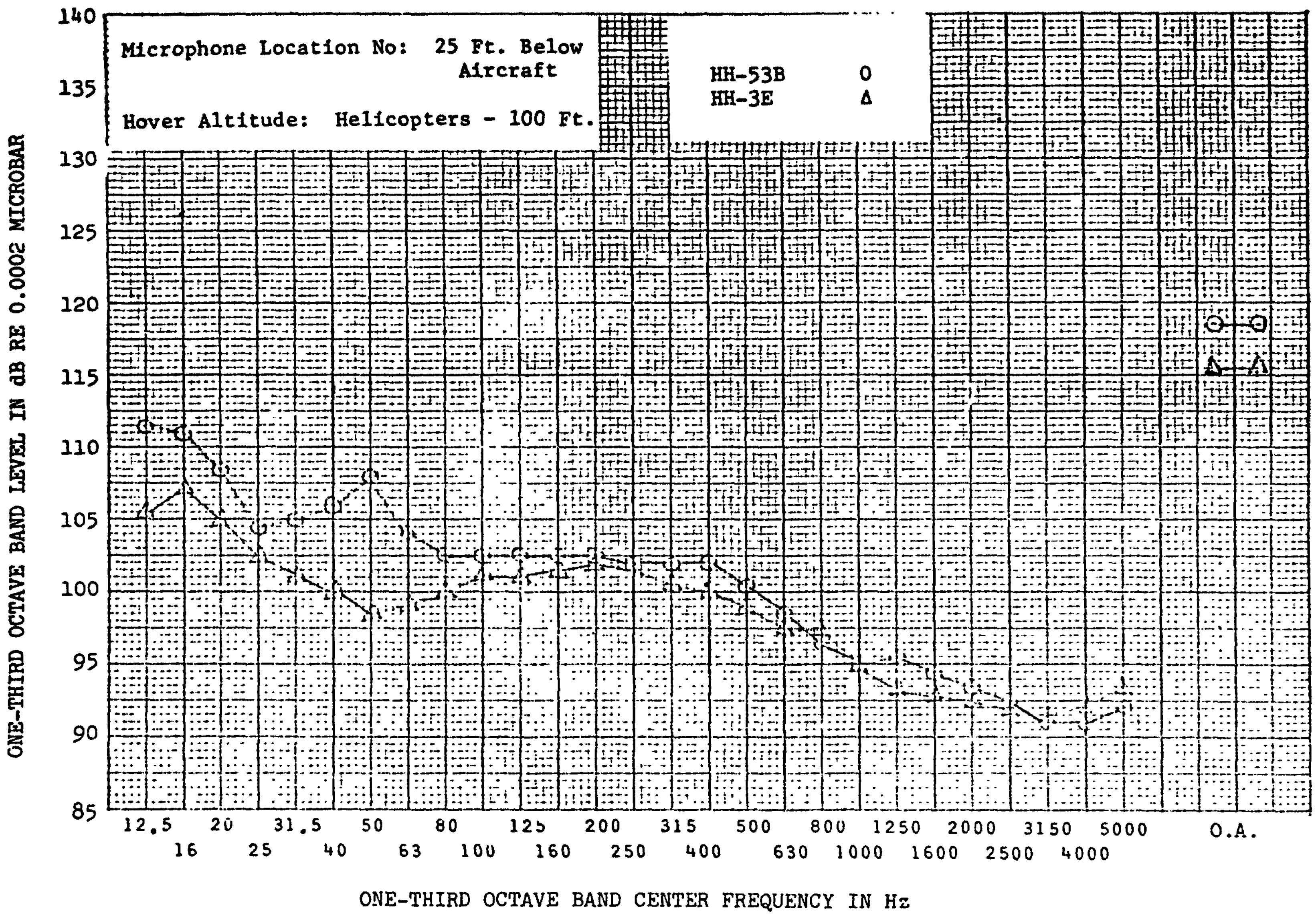


Figure 44 - Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

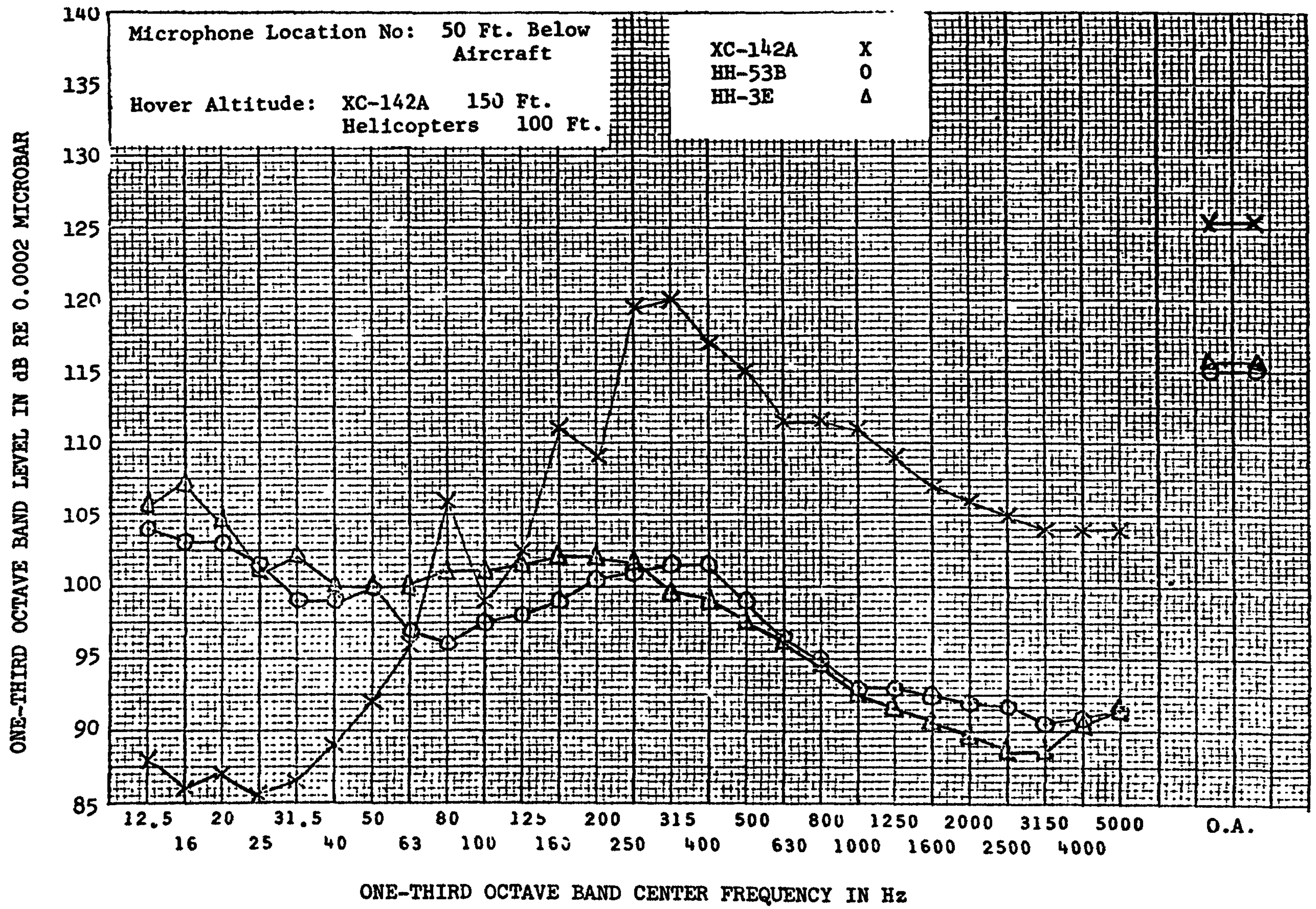


Figure 45 - Sound Pressure Level in 1/3 Octave Bands Below XC-142A, HH-53B and HH-3E Aircraft

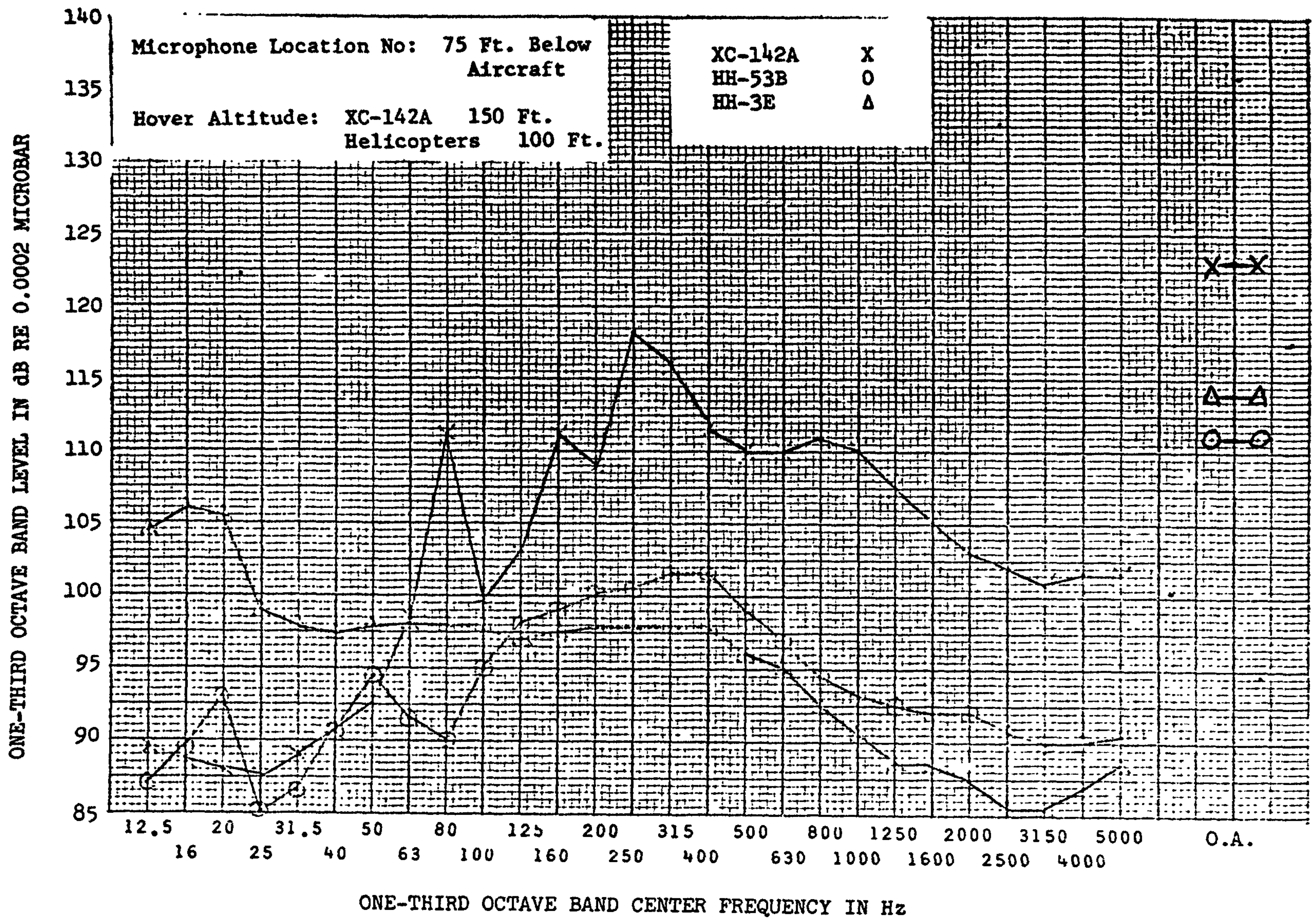


Figure 46 - Overall Sound Pressure Levels (dB) Below XC-142A HH-53B and HH-3E Aircraft

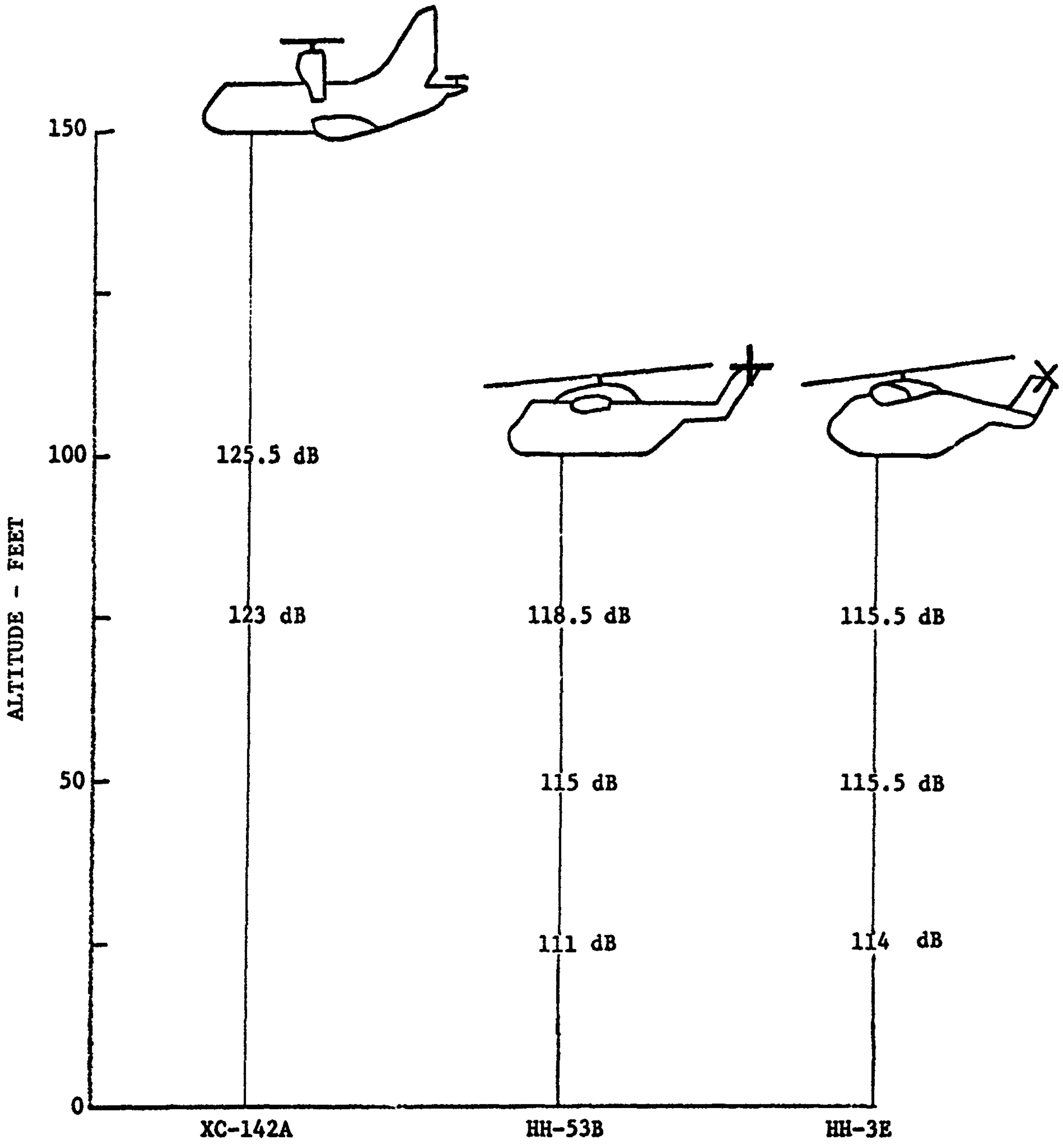


Figure 47 - Sound Pressure Level in 1/3 Octave Bands Below HH-3E Aircraft

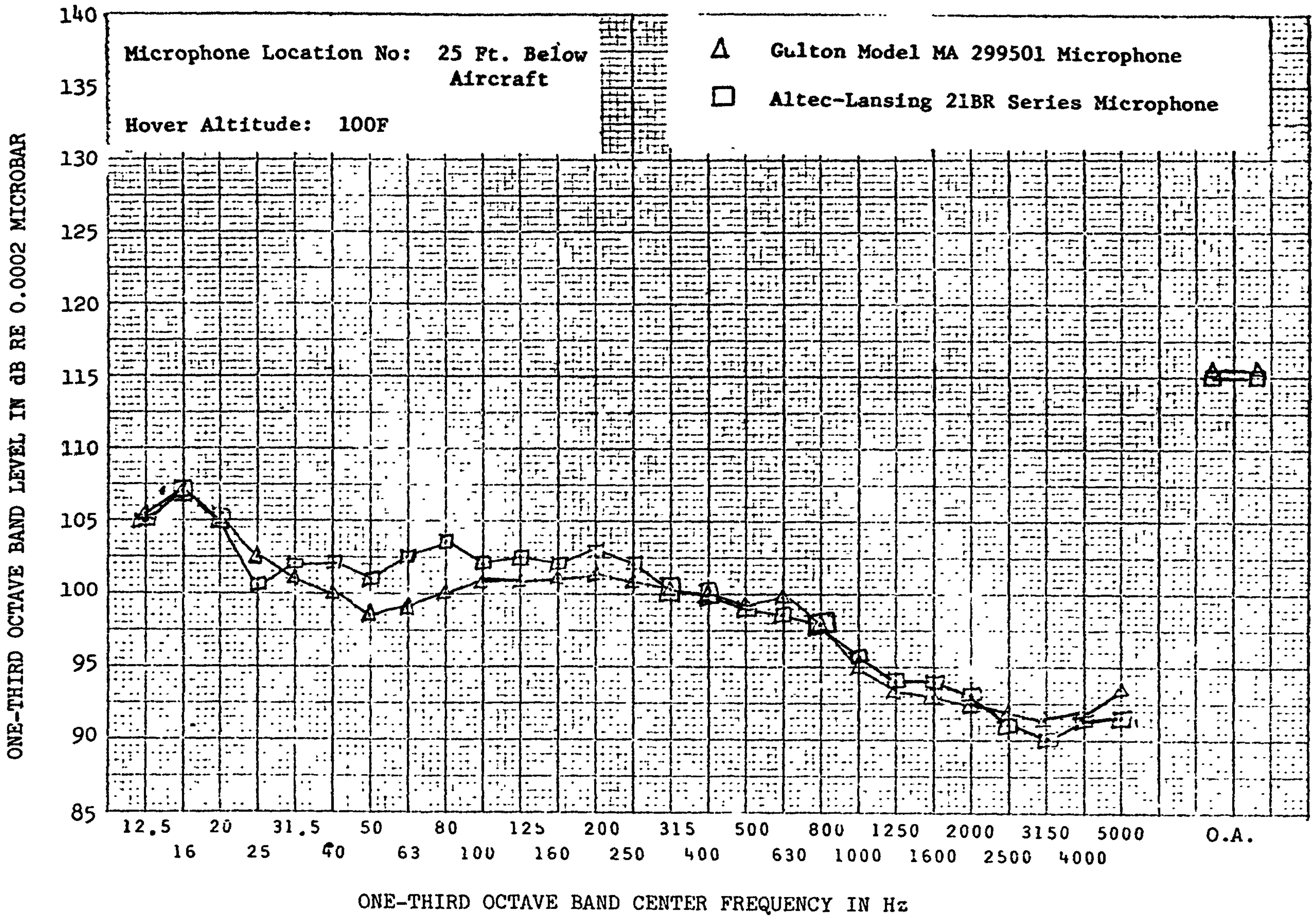


Figure 48 - Sound Pressure Level in 1/3 Octave Bands Below HH-3E Aircraft

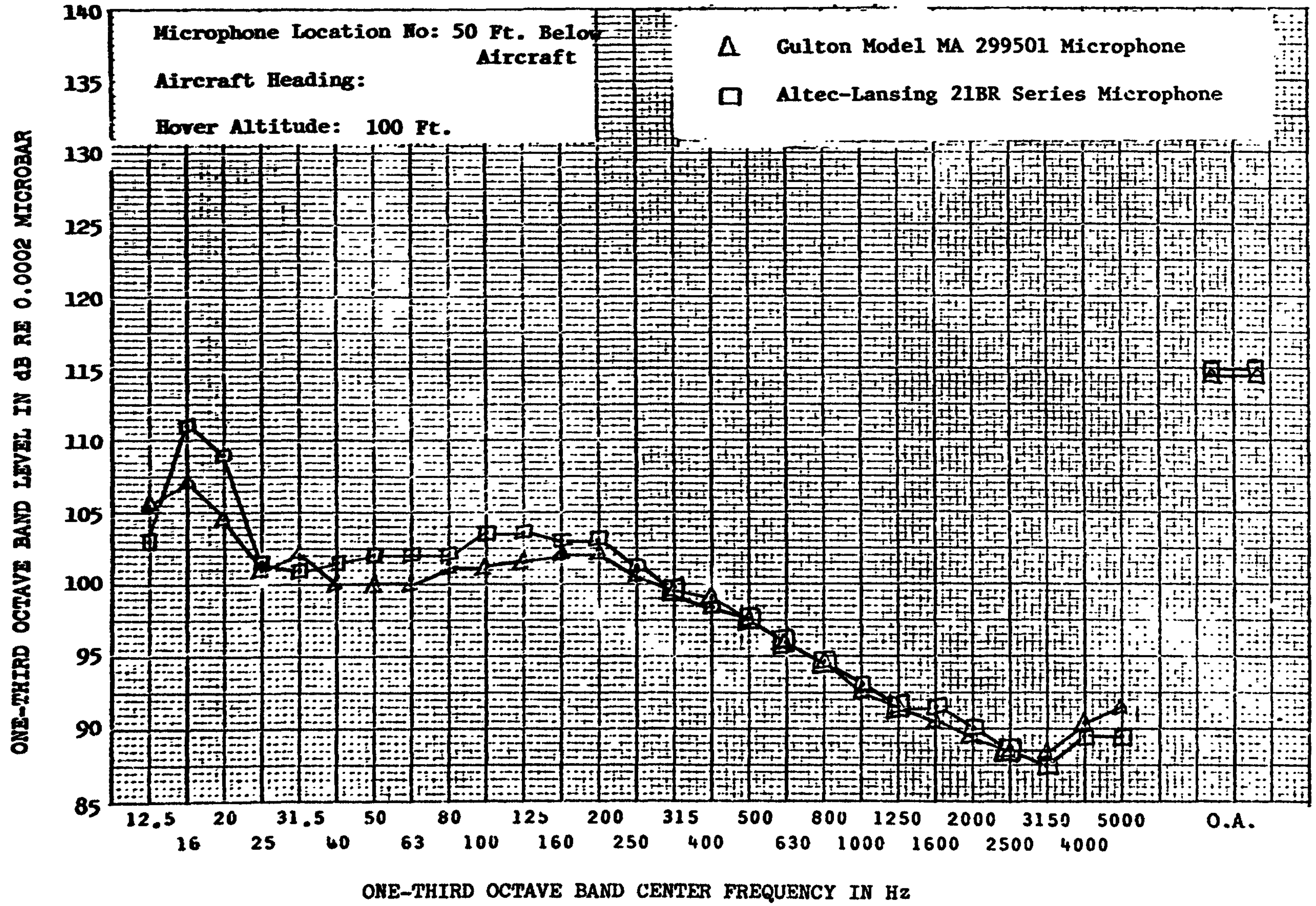


Figure 49 - Sound Pressure Level in 1/3 Octave Bands Below HH-3E Aircraft

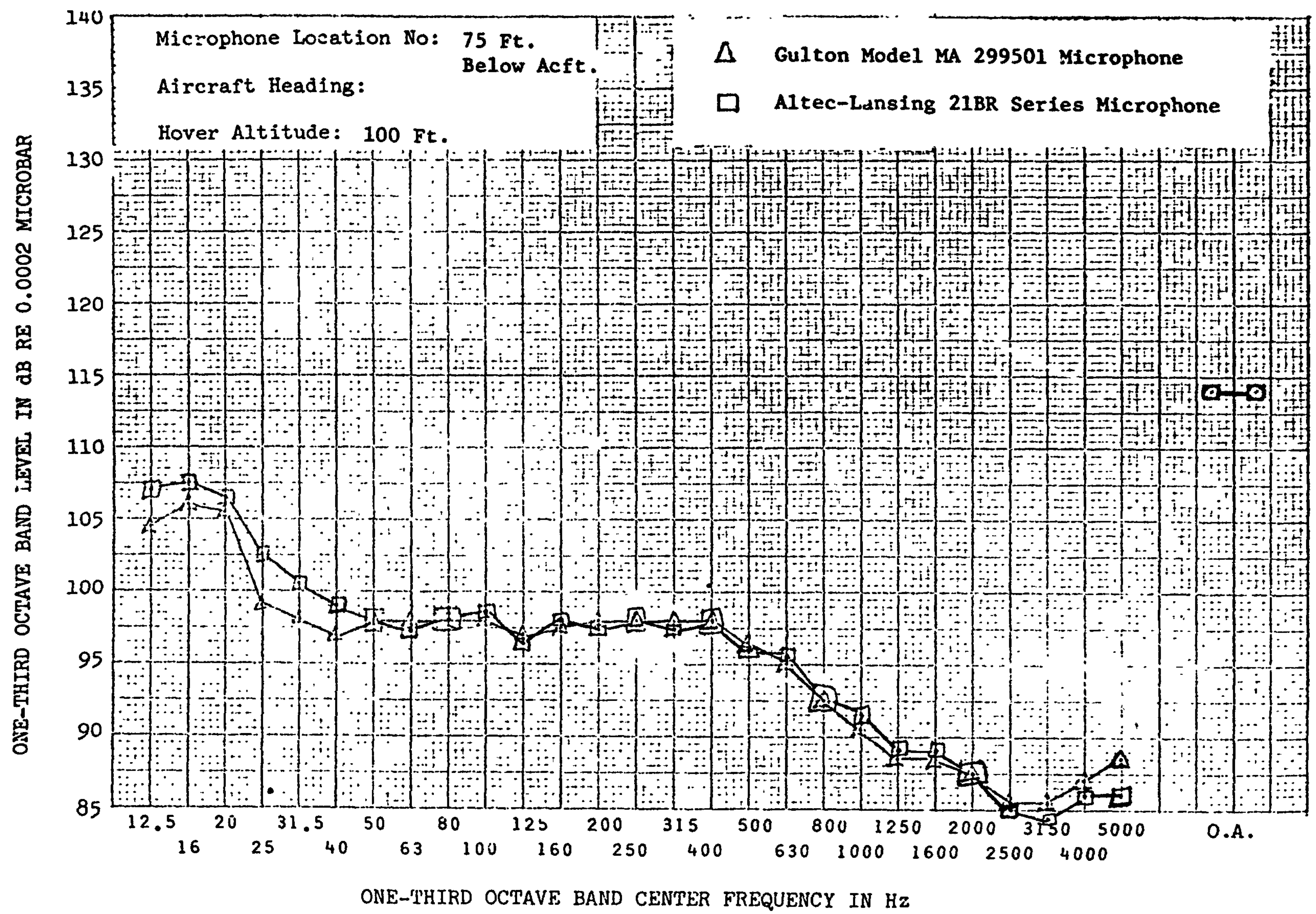
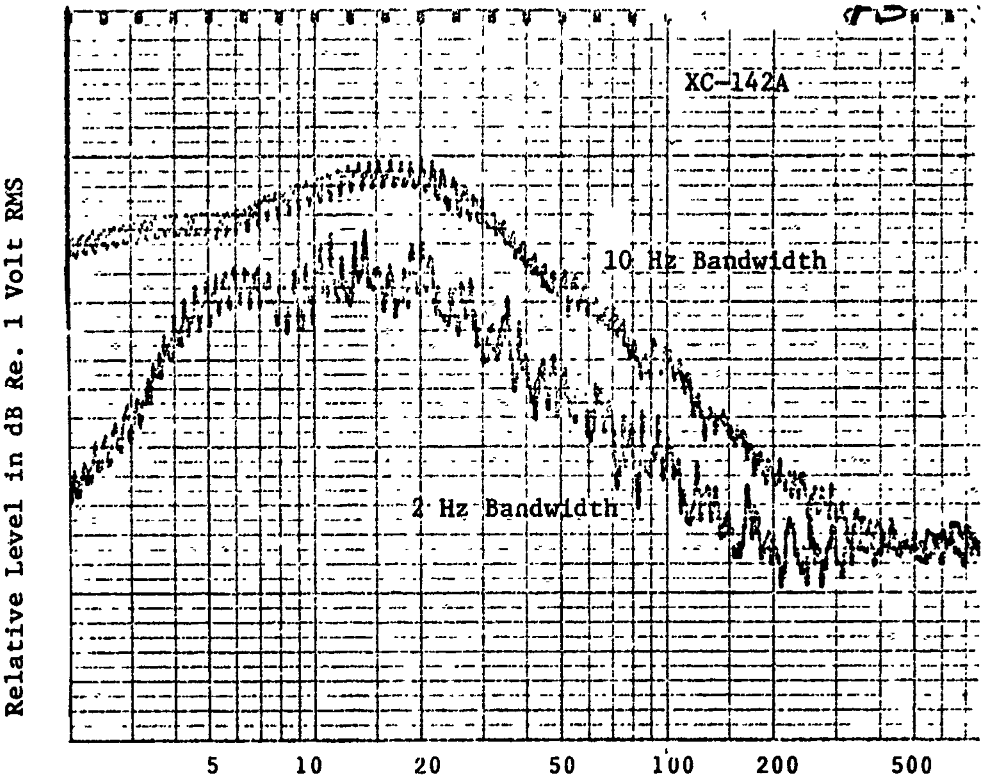


Figure 50 - Narrow Band Analysis of Sound Pressure Below the XC-142A and HH-53B Aircraft



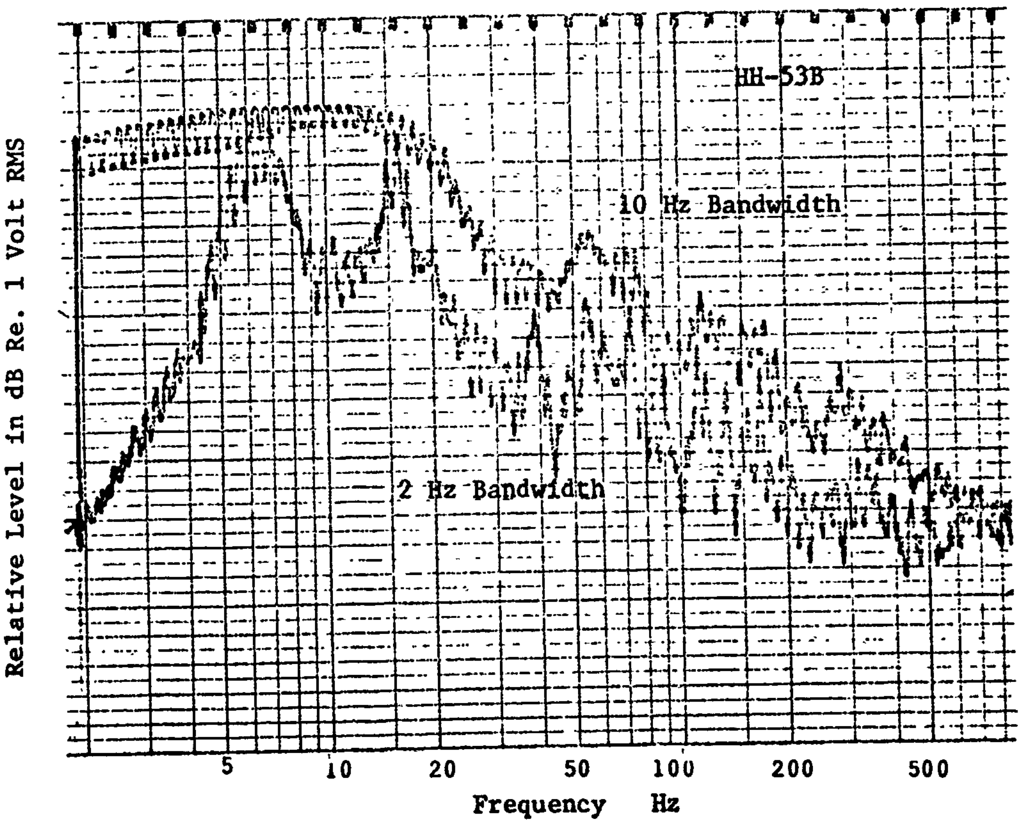


Figure 51 - AVERAGE DYNAMIC PRESSURES BELOW THE XC-142A, HH-53B AND HH-3E AIRCRAFT

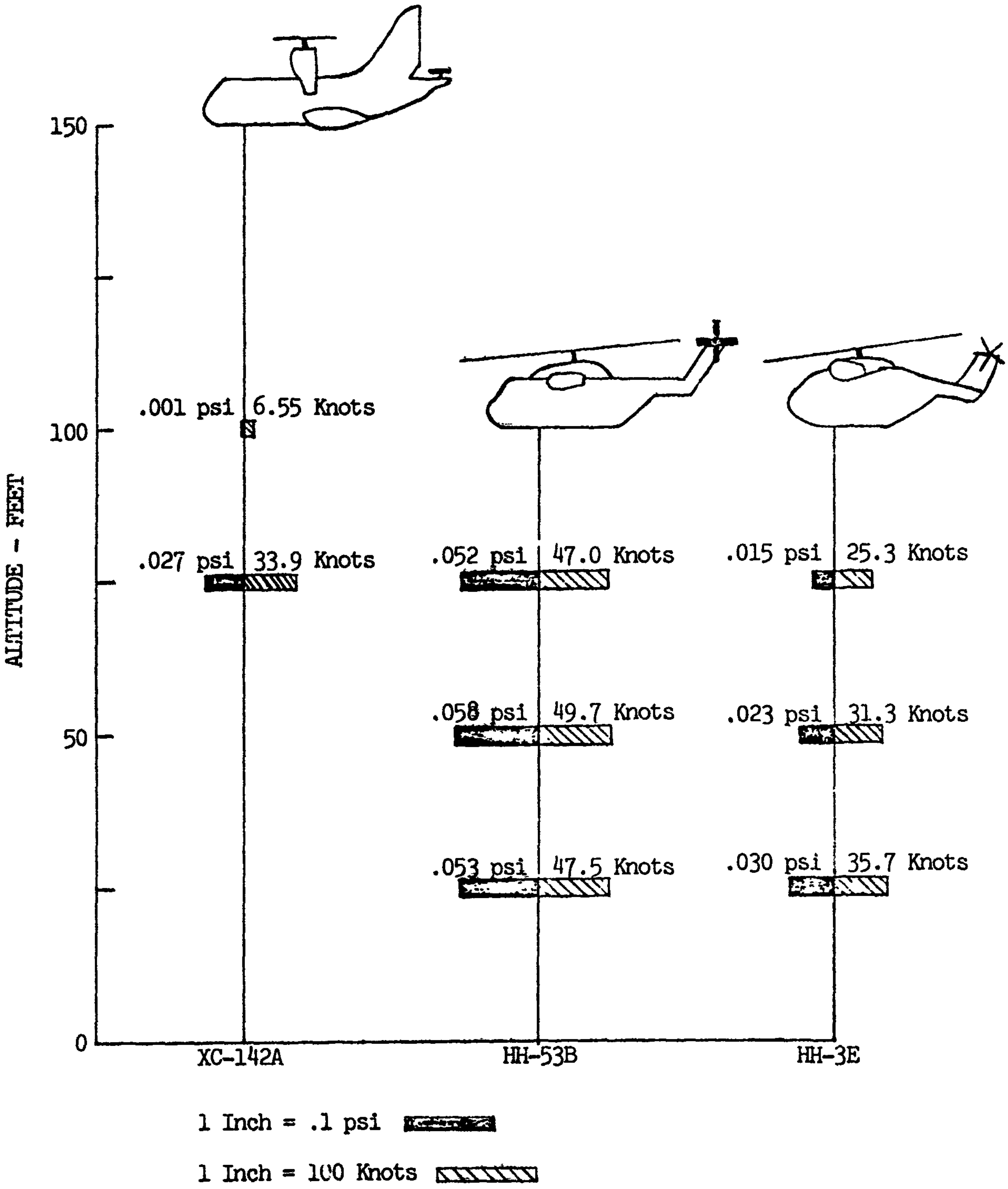


Figure 52 - Temperatures Below XC-142A, HH-53B, and HH-3E Aircraft

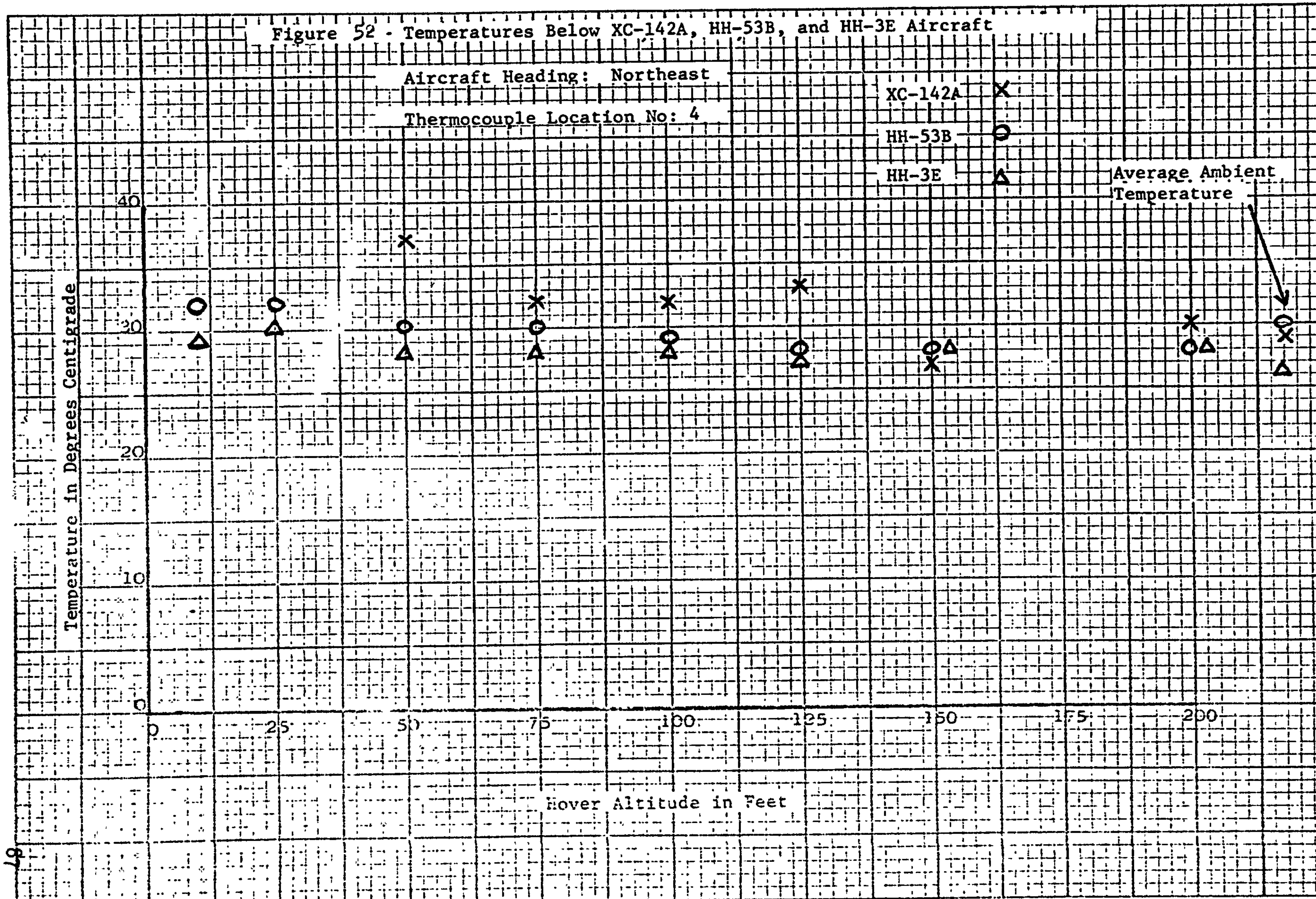
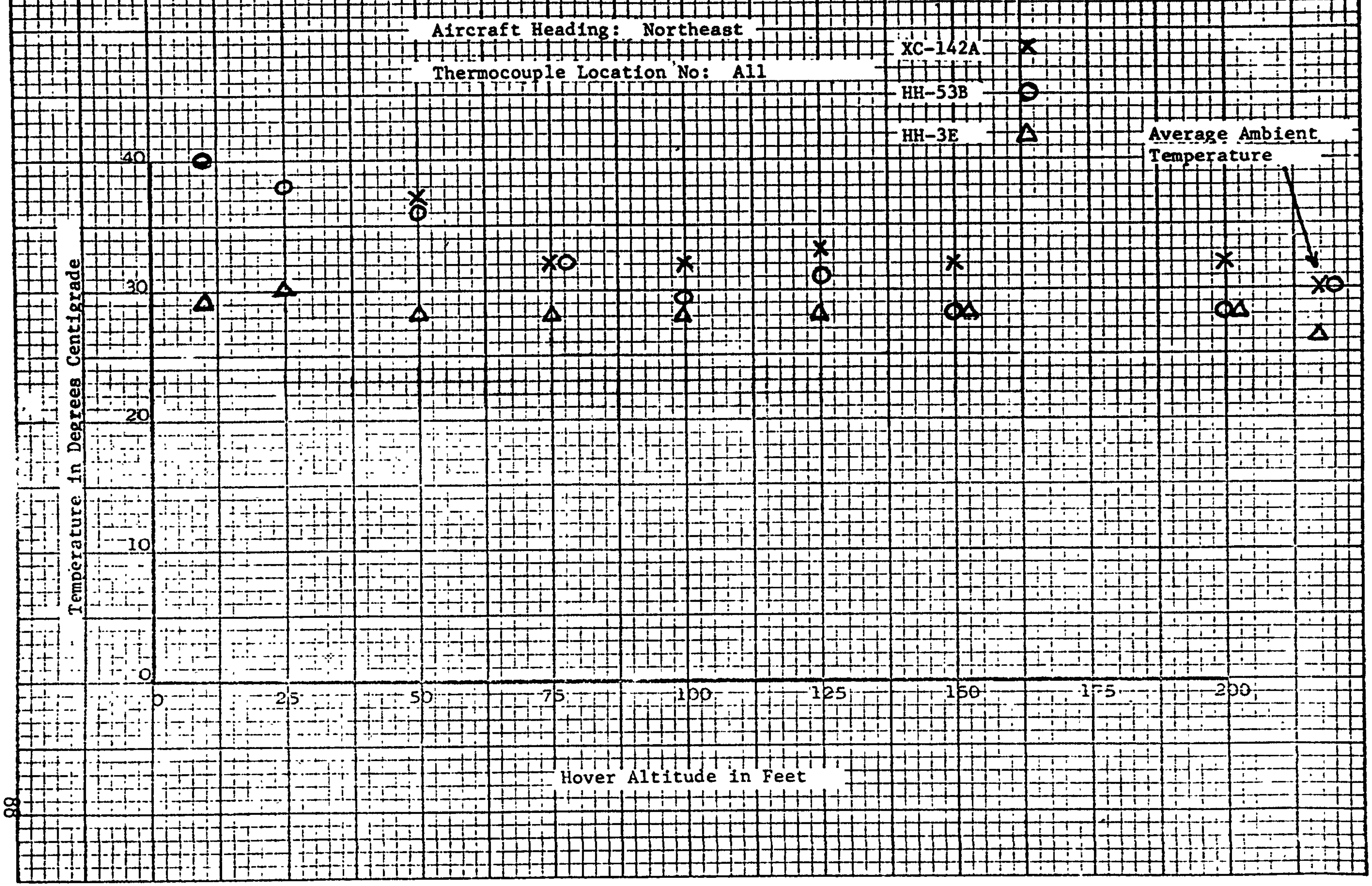


Figure 53 - Maximum Temperatures Below XC-142, HH-53B, and HH-3B Aircraft



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